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November 24,1998

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20544

EX PARTE NOTICE

Re: Ex Parte Presentation, ***Deployment of WirelineServices Offering Advanced Telecommunications Capability***
CC Docket No. 98-147

Dear Ms. Salas:

Pursuant to Section 1.1206 of the Commission's rules, enclosed are two copies for the referenced proceeding of an ex parte presentation that was made with FCC personnel on November 23, 1998. In addition to the undersigned Nortel Networks personnel attending the meeting were Gary Bolton (Senior DSL Business Manager), Wayne Getchell (Director, Subscriber Access Solutions), and Nabil Gebrael (Senior Manager, Data Access Regulatory and Standards Strategies). Doug Sicker (Office of Engineering and Technology) attended from the FCC. Discussion was based on the enclosed presentation, which was distributed at the meeting.

If you have any questions, please communicate with the undersigned.

Sincerely,

Raymond L. Strassburger
Director, Government Relations, Telecommunications Policy

Cc: Doug Sicker

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On guidelines for spectral compatibility of DSL technologies in the copper loop plant.

Introduction

Spectrum management in the loop plant has been recognized as a key component to maximize DSL service coverage and quality across the subscriber base and to maintain a spectral environment in the loop plant open to the introduction of new services.

Rules and guidelines are tools to ensure effective co-existence of high-speed DSL equipment with similar products in the field. To gain credibility with both service providers and equipment manufacturers, these rules and guidelines need to be based on recognized methods for assessing the impact of mixing xDSL technologies in the loop plant. Fortunately, there is industry experience in the development of xDSL standards[1] where such methods are employed in test suites to determine minimum performance requirements for standard-compliant equipment.

This document presents an overview of the methods employed to assess the compatibility of an xDSL technology with other xDSL technologies in the copper loop plant. This is followed by specific key examples, obtained using these methods, that benchmark the effect of interference from a relevant cross-section of xDSL Transmit PSDs (Power Spectral Densities) on the performance of standard xDSL systems in the same loop plant. A number of observations are drawn from the data in the examples which then lead to a set of recommendations to guide xDSL system deployment. Finally, answers to the specific questions posed by the FCC are provided; drawing from the material presented here.

[1] T1.413issue2; G.996.1Draft;

Methodology for Assessing Spectral Compatibility

Precise specification of these methods in a single xDSL-system-independent spectral compatibility standard is the focus of the Spectral Compatibility project in working group T1E1.4 of technical subcommittee T1E1. This document presents a methodology consistent with that being developed in the T1E1 technical subcommittee, for detailed crosstalk calculations to determine spectral compatibility[2].

The methodology is comprised of a number of elements which, when used together, can be used to illustrate the compatibility – or relative harm induced – by crosstalk from one type of xDSL system into other xDSL systems. These elements are:

1. a model for cable transmission characteristics, as a function of frequency
2. scenarios for xDSL service deployment as a function of loop length
3. models for near-end crosstalk (NEXT) and far-end crosstalk (FEXT) as a function of frequency and loop length
4. Tx PSD masks based on established and impending xDSL standards
   - once the effects of crosstalk from these sources have been established, the impact of any new xDSL system that meets any one of these can be bounded
5. models of established and emerging standards-based xDSL receivers that are used to determine the performance of these systems, in the presence of crosstalk noise with a given PSD

A discussion of each of these elements follows below.

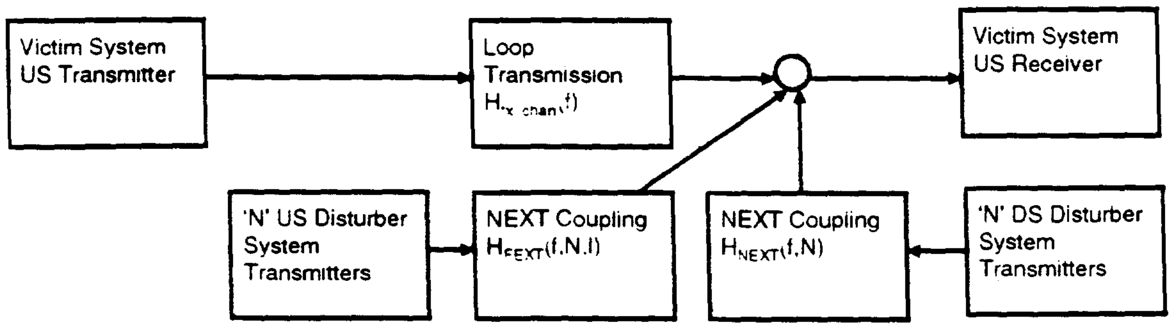


Figure 1 - Overall Crosstalk Evaluation Model

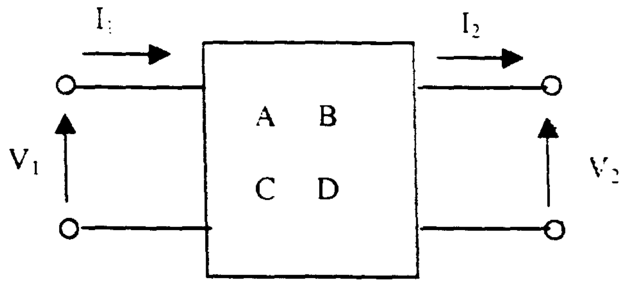
[2] T1E1.4/98-002, Proposed Working Draft of Spectrum Compatibility Technical Report, June1-5,1998

Loop plant models

The present industry standard for computing the insertion loss of twisted pair copper telephone loops for xDSL service was laid down in the 1970's with the publication by the Bell Telephone Laboratories of the primary cable constants of RLGC for frequencies from 1 Hz to 5 MHz[3]. These parameters can be found in ANSI T1.601-1992 Annex G.

From these constants, a two-port model of each section of telephone cable may be computed. Two-port models relate the input port voltage and current to the voltage and current at the output port. The most convenient two-port model is this case is the chain-matrix ABCD parameters which can be cascaded to compute the end-to-end transmission characteristic of a subscriber loop.

The ABCD parameters are defined as follows:



Where:

$$V_1 = AV_2 - BI_2$$
$$I_1 = CV_2 - DI_2$$

The ABCD parameters of each individual line sections of the loop are computed using the following equations based on the transmission line theory.

$$A = \cosh(\gamma l)$$
$$B = Z_0 \sinh(\gamma l)$$
$$C = \frac{1}{Z_0} \sinh(\gamma l)$$
$$D = \cosh(\gamma l)$$

Where l is the section length, γ is the propagation constant per unit distance, and Z_0 is the characteristic impedance.

[3] In ANSI T1E1.4 efforts on VDSL, a FTTC system, which will require higher frequencies, have lead to a consensus for the method to compute the primary constants for the copper twisted pair plant at frequencies up to 30 MHz. This method can be found in T1E1.4/97-131R2 Section 8, Appendix-RLCG Characterization (A).

Similarly, the ABCD parameters of each individual bridged tap are computed using the following equations.

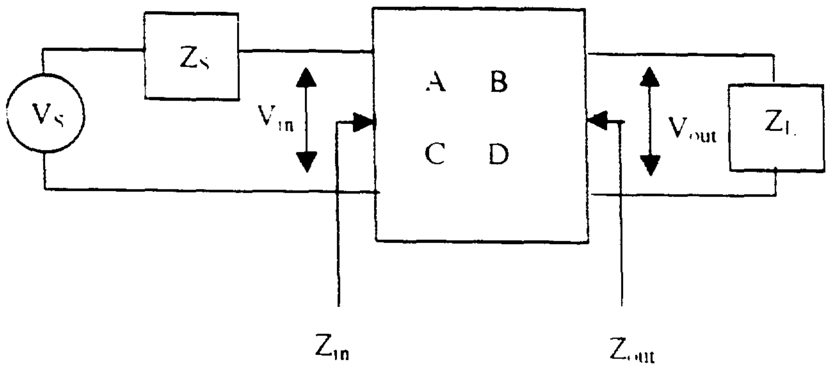
$$A = 1$$
$$B = 0$$
$$C = \frac{1}{Z_0}\tanh(\gamma l)$$
$$D = 1$$

The transmission line parameters of the cable sections and of the bridged taps are computed from the RLGC primary parameters using the following equations.

$$Z = R + j\omega L$$
$$Y = G + j\omega C$$
$$Z_0 = \sqrt{Z/Y}$$
$$\gamma = \sqrt{ZY}$$

Where R, L, G, and C are the primary cable constants per unit distance for each frequency analyzed.

Finally, the loop insertion loss as a function of frequency can be computed as follows.



$$Z_{in} = \frac{AZ_L + B}{CZ_L + D} \qquad Z_{out} = \frac{DZ_S + B}{CZ_S + A}$$

$$V_{in} = V_S\frac{Z_{in}}{Z_S + Z_{in}} \qquad V_{out} = V_S\frac{Z_L}{AZ_L + B + CZ_S Z_L + DZ_S}$$

$$\text{Loop Insertion Loss} = \frac{Z_L + Z_S}{AZ_L + B + CZ_S Z_L + DZ_S}$$

The above technique has been proven in during the development of the ANSI Standard T1.601, by comparison of measured and computed insertion loss, by a number of organizations including Bellcore and Nortel.

DSL Deployment Scenarios

Once the loop models have been established a set of deployment scenarios or test cases must be established. These scenarios are a combination of loop definitions with a technology mix that may be implemented on them. In the analysis that follows, we have selected the following two scenarios:

Business Scenario: This is based on technologies which are likely to be used in business applications covering users within the Carrier Serving Area (CSA - 9kft of 26AWG). In the business scenario services such as ISDN, HDSL, T1, ADSL and others are expected.

Residential Scenario: Residential loop lengths are considered which reach the maximum working length of cable that can be expected to be free of loading coils (15kft 26AWG). For residential applications such services as ISDN, ADSL and G992.2 (G.lite) among others are expected. Although HDSL is not intended for residential use; HDSL disturber analysis is included here to show effect of "HDSL Tx PSD like" services which could exist in the future.

To gauge these lengths[4] against a view of the overall loop plant make-up, the following chart is considered. This shows the cumulative distribution of length of subscriber lines in Bell Canada's loop plant as captured in a 1987 characterization report. From the scenarios described above it can be seen that the business scenario covers approximately 60% of the business lines (see note below) whereas the residential case provides data which covers over 80% of residential lines.

[4] The chart above is for physical line lengths which consist of a mix of both 26 and 24 AWG cable. A length of pure 26AWG cable will correspond to a somewhat longer line of mixed gauges in this chart.

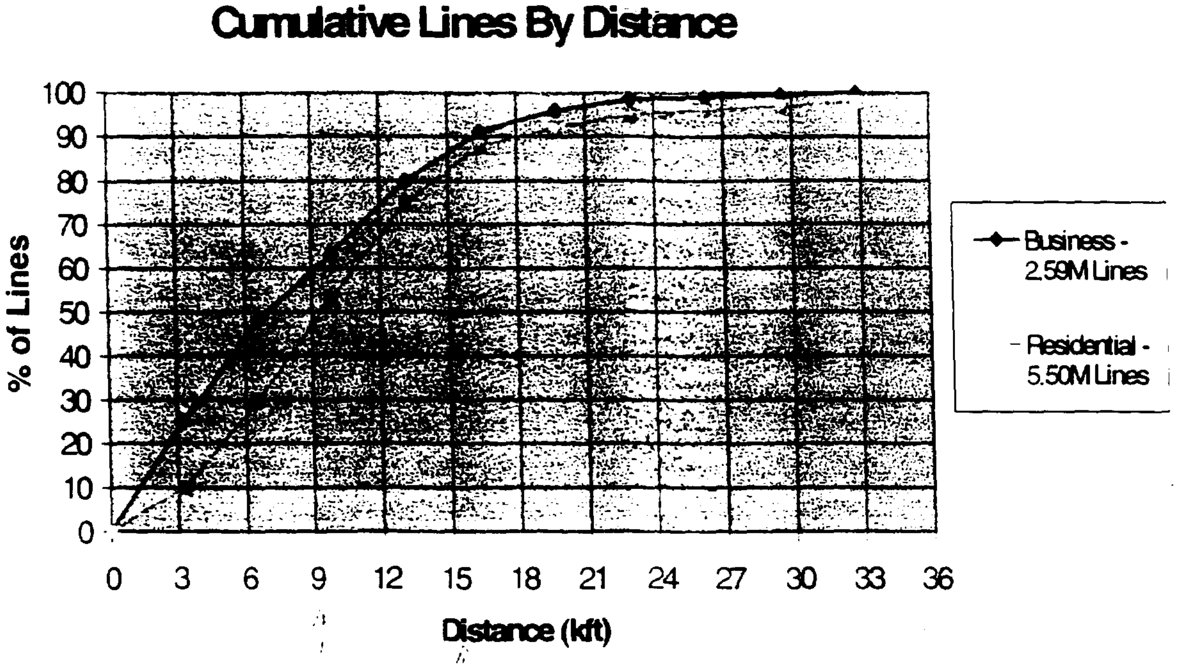


Figure 2 – Cumulative Distribution of Length of Subscriber Lines

Crosstalk

Crosstalk is defined as interference from a signal applied to one transmission channel affecting a receiver located on another transmission channel. To this effect it represents un-intentional reception of the disturbing signal.

In the case of xDSL systems operating in the telephone network, the transmission channels are made of twisted copper pairs that are assembled in transmission cables. Large cables, with high pair counts, are constructed by first grouping individual pairs in units or binder groups and then assembling those groups to form the cable. Depending on the cable final pair count, binder groups can contain 25, 50, or 100 pairs.

The interference coupling path between two pairs within a cable is a function of the parasitic elements between those two pairs and of the electro-magnetic field produced by the disturbing signal and surrounding the disturbed signal, it is therefore greatly influenced by the quality of each pair's longitudinal balance.

Two types of crosstalk are commonly defined depending on the relative location of the disturbing and the disturbed systems. Transmission systems frequently use a channel that spans some physical distance while carrying multiple signals in both directions. In this case, transmitters located at the same end as the disturbed receiver generate near-end crosstalk (NEXT), while transmitters located at the opposite end as the disturbed receiver generate far-end crosstalk (FEXT).

It is relatively easy to measure the crosstalk coupling loss between any combination of two pairs but this creates a large number of results. Typically those results will vary with the test frequencies in use and with the cable section under consideration. It is possible to reduce the number of results by calculating the combined effects of 'n' disturbers into a disturbed pair. Because noise adds in power terms as opposed to voltage terms, the sum of all interfering signals affecting one receiver is called the Grand Power Sum (GPS) of the NEXT or FEXT coupling losses.

Assuming that all disturbers have the same signal level, the noise affecting one pair can be fully described by the GPS of all other pairs into this pair under consideration. However, even this leads a large number of values as each disturbed pair will have a different GPS and will also see large variations at different frequencies. The solution, as often done with large populations, is to only consider the statistical behaviour of the crosstalk coupling loss GPSs.

If a large population of coupling loss GPSs is analyzed by statistical means, it is found that the frequency variation seen at any percentile point of the NEXT and FEXT GPS distribution reduces to the simple relations of 15 dB per decade and 20 dB per decade respectively. Moreover, if the 99-percentile points are used, it is found that the variation with the number of disturbers reduces to the simple equation of $6*\log_{10}(n)$.

These characteristics of the 99-percentile GPS distribution have been used to define equations for the 1% worst case NEXT and FEXT over frequency and with variable number of disturbers. These are the equations given below as contained in Annex B of T1.413 issue 2. They are useful in assessing the worst case impact of NEXT and FEXT over a disturbed system.

A noticeable difference between NEXT and FEXT interference is that when the cable reaches a certain distance (which is a function of frequency), the NEXT level becomes totally insensitive to the cable length. FEXT on the other hand has a more complex relation with the cable length.

FEXT is a function of the length, l, of the coupling span and the frequency response, $H_{channel}(f)$, over that length. The FEXT coupling model is given by

$$|H_{FEXT}(f)|^2 = k_n \, l \, f^2 \, |H_{channel}(f)|^2$$

Where k_n is the coupling constant and l is the coupling path length. For $n < 50$, l in feet, f in Hertz, and 1% worst-case coupling loss, $k_n = 0.7744 \times 10^{-20} \times n^{0.6}$ where n is the number of interferers. The coupling increases as $10*\log_{10}$ of the distance which causes an increase in the noise level on longer cables; on the other hand, the noise path includes the signal path attenuation which increases as the cable gets longer. The net result is that FEXT levels drop as the cable length increases.

NEXT, on the other hand, is insensitive to cable lengths that are of interest here, and is given by

$$|H_{NEXT}(f)|^2 = x_n f^{3/2}$$

Where x_n is the coupling constant. For n < 50, l in feet, f in Hertz, and 1% worst-case coupling, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$ where n is the number of interferers.

When the FEXT noise is computed for a victim xDSL system (the system being interfered with), on a given loop length, the coupling path length, l, is usually assumed to be the same as the loop length of the victim system. In the upstream (CPE -> CO) path, this presumes that all far-end disturbers are at the same distance from the CO as the disturbed system transmitter. The Nortel analysis assumes a less optimistic model for the location of upstream FEXT sources, that is a function of the victim system loop length[5].

These formulae are a function of the number of disturbers and the statistical likelihood of the coupling from n disturbers exceeding some threshold on a specific victim pair.

Accounting for the 1% worse-case permits deployment of highly reliable, high coverage systems with a minimum of loop engineering and with margin for unknown or secondary impairments (e.g. AM radio ingress, in-home wiring, impulse noise ...). It must not be confused, however, with providing a view of the performance seen on a typical loop pair.

The following graph has been generated using an assumption of normal distribution on a dB scale for both of the pair-to-pair and power sum distributions. It shows all distributions from individual losses to 49-disturbers GPS with all the intermediate cases of 2, 3, 4, etc disturbers GPS. In this case, NEXT[6] coupling losses at 80 kHz have been used and the statistical distributions are such that for 49-GPS, the mean (m) is 63.4 dB and the standard deviation (σ_{GPS}) is 2.75 dB for a 1% value of 57 dB as defined in T1.413 issue 2. The case of 1-GPS, which is equivalent to pair-to-pair losses, has values of m = 86.4 dB and σ_{GPS} = 7.80 dB for a 1% point of 68.3 dB.

The Wilkinson equations have been used to relate the pair-to-pair coupling losses distribution to the n-GPS distribution. These equations are accurate for the case of non-truncated normal pair-to-pair losses and GPS distribution on a dB scale and are as follows.

$$m_{GPS} = m - 10\log_{10}(n) - \frac{\lambda\sigma^2}{2} + 5\log_{10}\left[1 + \frac{\left(e^{\lambda^2\sigma^2} - 1\right)}{n}\right]$$

[5] K.Harris et al. "Proposal for Short Loop remote power Cutback in G.lite", Nortel Universal ADSL Working Group (UAWG) Contribution, TG/98-329r1, September 19-20, 1998

[6] This discussion of the statistical nature of crosstalk noise power figures is also applicable to FEXT.

$$\sigma_{GPS} = \frac{10}{\lambda}\log_{10}\left[1+\frac{e^{\lambda^2\sigma^2}-1}{n}\right]$$

$$\text{Where} \quad \lambda = \frac{1}{10\log_{10}(e)}$$

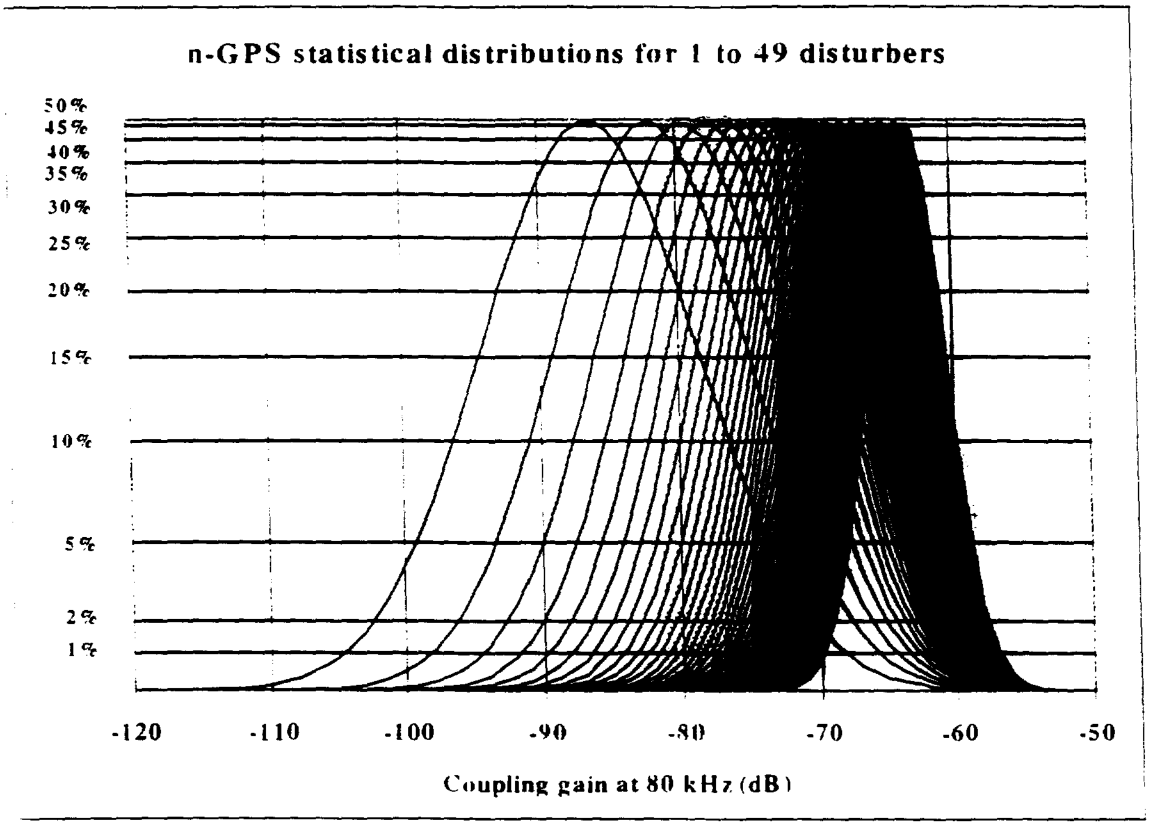


Figure 3 – Statistical Spread of GPS in a 50 Pair Binder Group

Coupling gains have been represented in the above figure as opposed to coupling losses as described so far to permit a graphical representation where lower noise levels are shown on the left hand side. The T1.413 noise equations for the 1% worst case coupling and for 1 to 49 disturbers are represented by the locus of points at the intersection of the 1% horizontal line and all of the 1 to 49-GPS curves in the bottom right-hand side corner of the figure.

Other statistical distributions may be used to represent the variations of the n-GPS NEXT to be expected from a population of twisted pairs affected by n disturbers, but the same conclusion will hold. The case of the 1% worst case coupling loss represents the 1% likelihood that any single loop will experience crosstalk coupling worse than this. One trend that is very apparent from the figure is that the statistical spread between best-case, average, and worst-case noise levels increases when the number of disturbers reduces.

All of the above discussion applies to the case of NEXT and FEXT crosstalk involving disturbing and disturbed systems located within the same binder group. The same discussion can be made for coupling between binder groups. The 10 dB increase of coupling loss usually quoted applies to the 99-percentile point of the GPS distribution for 49 disturbers. A wide statistical spread will be seen as other percentiles are used or if the number of disturbers is changed.

The formulae for NEXT and FEXT presented above may be also extended to cover the case of more than one disturber type; however, that must be done accounting for the fact that both sets of interfering systems cannot simultaneously occupy the worst case 'space'[7].

The conclusion that can be drawn from the above discussion is that in evaluating spectral compatibility between two different systems, the usual 99-percentile worst case coupling loss can be used to assess the minimum likely data rate achievable (on a rate-adaptive system). Average users will be expected to achieve higher rates, though these cannot be determined apriori. This does suggest that the presence of legacy systems in the phone network that create high levels of interference can be tolerated if they are statistically rare. The presence of such systems should not be used to authorize the introduction of new systems creating comparable noise levels, if the new systems are intended to be deployed on a large scale.

[7] J.Cook, BT, "NEXT and FEXT noise calculation: comparison of methods", BT Contribution, T1E1.4/98-242, Aug.31-Sept.4, 1998.

Candidate Disturber Tx PSD masks based on standard xDSL systems

A number of proposals[8] have been tabled suggesting use of multiple PSD masks that may be used to establish spectral compatibility of a given xDSL technology, These proposals have suggested that spectral compatibility be declared if it can be shown that the transmit PSD of the candidate xDSL technology is contained within any one of a number of 'standard' PSDs. These include:

A. ISDN Tx PSD
   - Mask corresponding to the PSD of ISDN Basic Access (BA) transmit signal

B. T1.601[9]-mask
   - Mask corresponding to the upper bound of PSD of signal from a [ISDN BA] NT at interface (Note: not the same as actual 'ISDN Tx PSD' above)
   - Included here as it has been proposed[10] as an allowable Tx PSD mask for xDSL systems[11]

C. HDSL Tx PSD
   - Mask corresponding to the PSD of an HDSL system transmit signal

D. T1.413issue2 non-overlapping spectra full-rate DMT ADSL mask (denoted 'T1.413-FDD mask')
   - Separate upstream (US: CPE->CO) and downstream (DS: CO -> CPE) masks
   - Masks for overlapped spectra operation are also shown in figures below. These have not (yet) been proposed as part of any compatibility standard.

E. G.992.2 non-overlapping spectra splitterless DMT ADSL mask (denoted 'G.992.2-FDD mask')
   - Separate upstream (US: CPE->CO) and downstream (DS: CO -> CPE) masks

F. T1 Tx PSD
   - Mask corresponding to the PSD of a T1 system transmit signal

These PSDs are shown in Figure 4 - Figure 12.

We will use these masks to determine crosstalk noise into standard xDSL systems and the resulting impact on those systems. ***It is important to note that these masks cover not only the standard systems from which they derive, but also any other xDSL systems which claim to conform to the same masks.***

It is informative to consider the resulting near-end crosstalk (NEXT) signal PSDs corresponding to these transmit PSDs – see Figure 4 - Figure 12. Given that NEXT coupling is more significant than FEXT coupling, one might anticipate the outcome of mixing xDSL systems in the same binder group where the xDSL equipment receives in the

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[8] G.Zimmerman, "Normative Text for Spectral Compatibility Evaluations (Revised)", PairGain Technologies Contribution, T1E1.4/98-305, Aug.31, 1998.

[9] Using extended PSD mask from draft of ANSI T1.601-1998 (see T1E1.4/98-004R1)

[10] Paradyne FCC part 68 waiver application

[11] The T1.601 specification also constrains the total Tx power to 14dBm maximum. A transmitter that meets the T1.601 PSD mask at all frequencies will actually exceed this total transmit power limit.

same frequency band as adjacent near-end xDSL systems transmit. All NEXT curves assume 1 disturber with the 1% worst-case coupling.

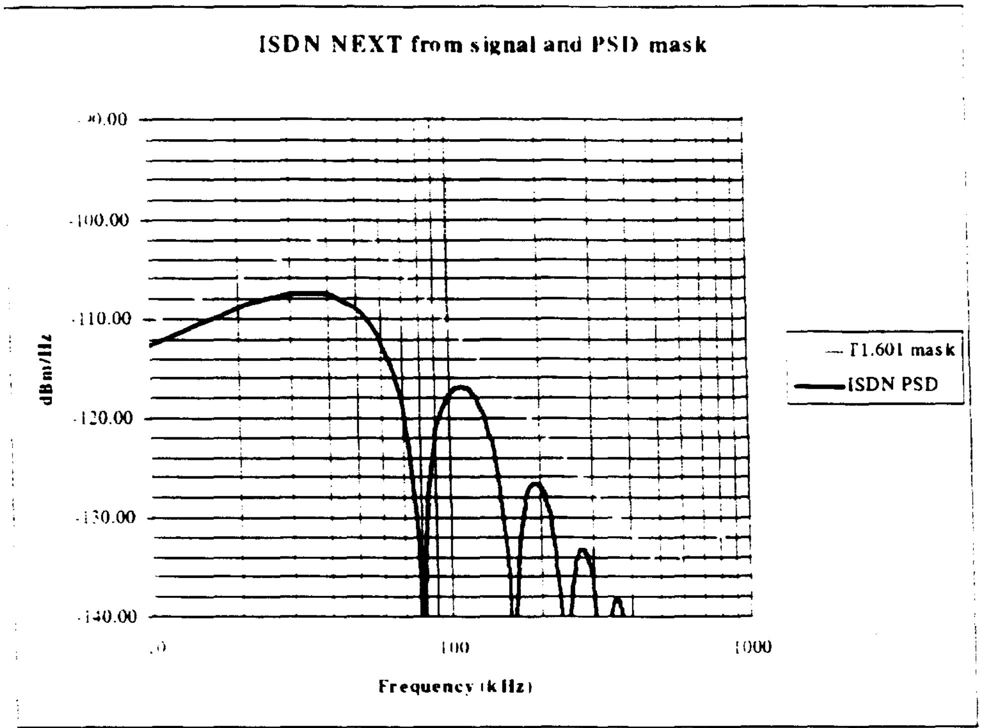

Figure 4 - PSDs corrsponding to ISDN Transmitter and to T1.601 Mask

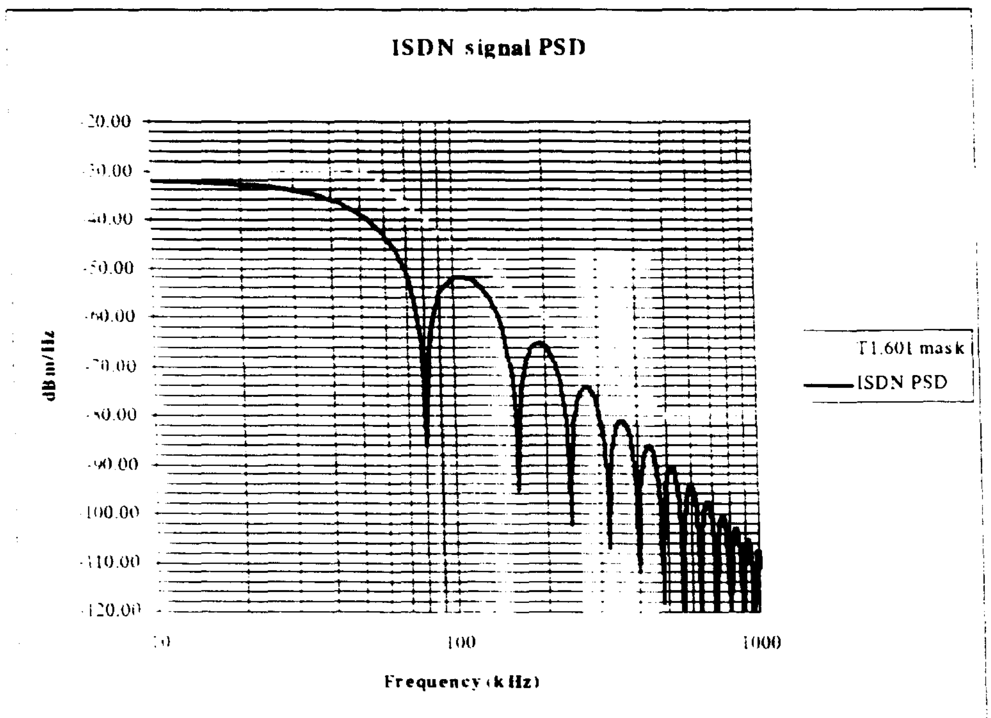

Figure 5 - NEXT PSDs corrspondning to ISDN Transmitter and to T1.601 Mask

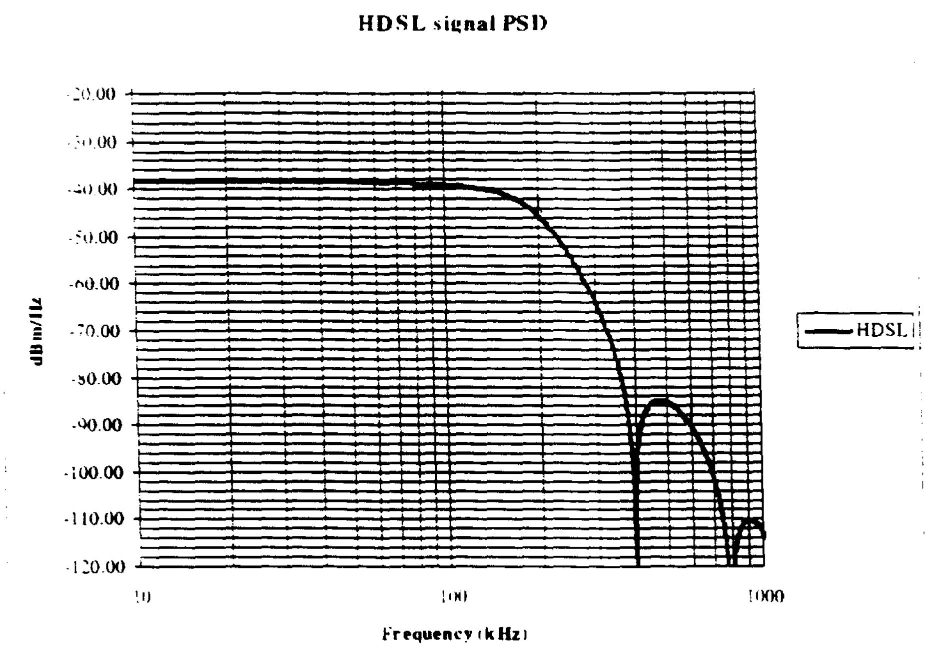

Figure 6 - PSD corrsponding to HDSL Transmitter

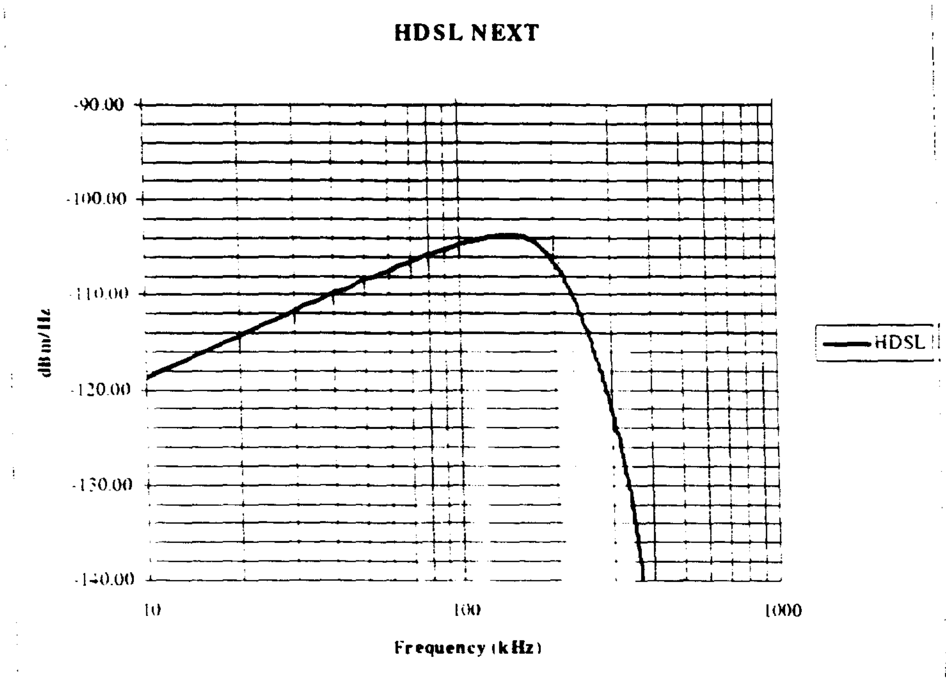

Figure 7 - NEXT PSD corrsponding to HDSL Transmitter

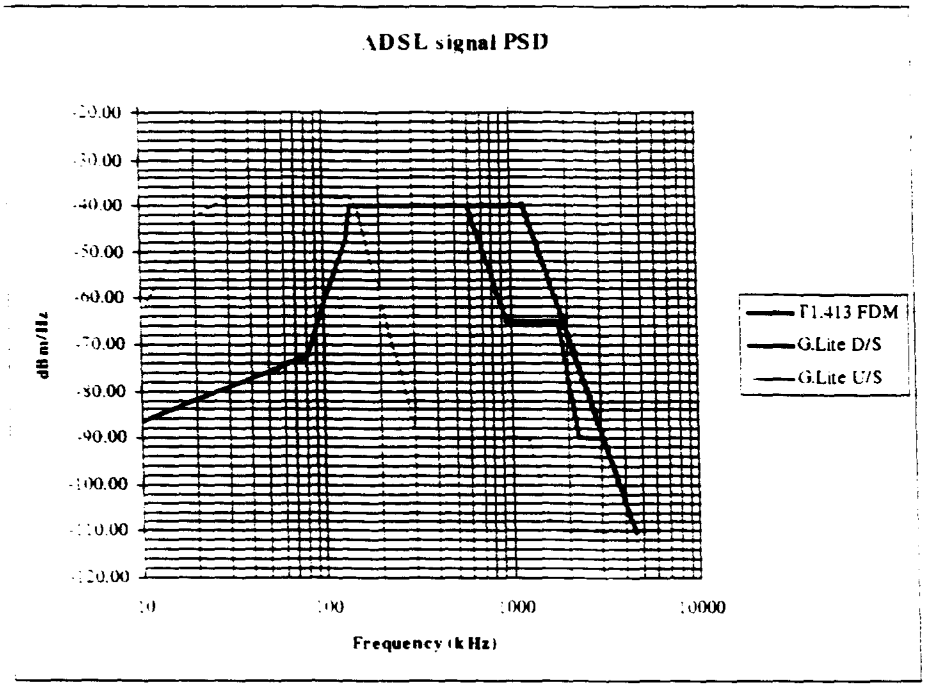

Figure 8: Upstream and Downstream Tx PSD Masks for Non-Overlapped Spectra Operation (FDD) of T1.413 and G.992.2 (G.lite)

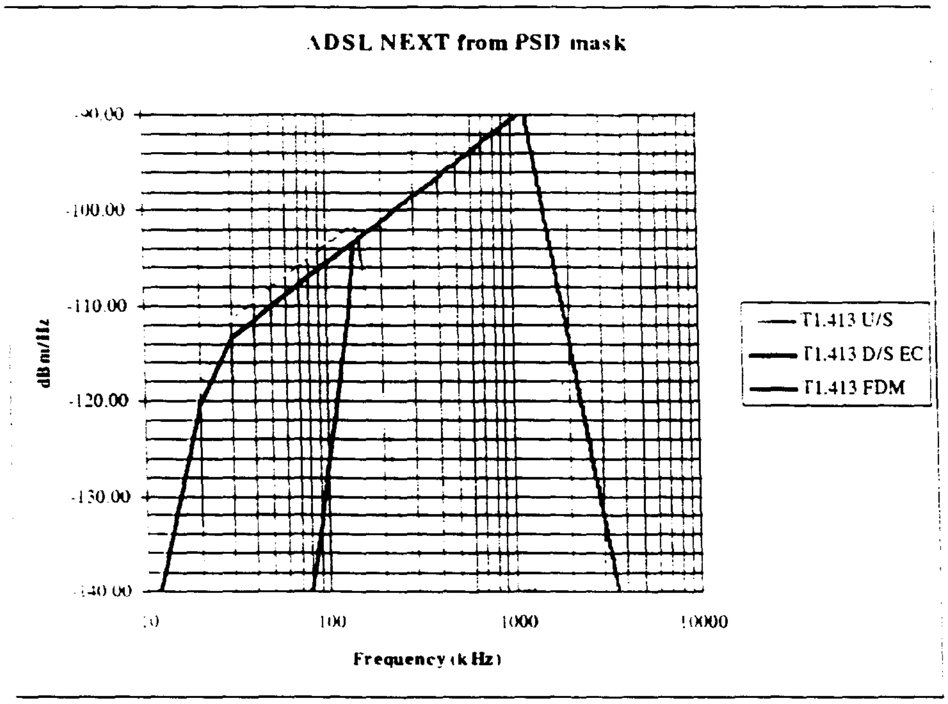

Figure 9 - NEXT for T1.413 PSD (EC and FDD)

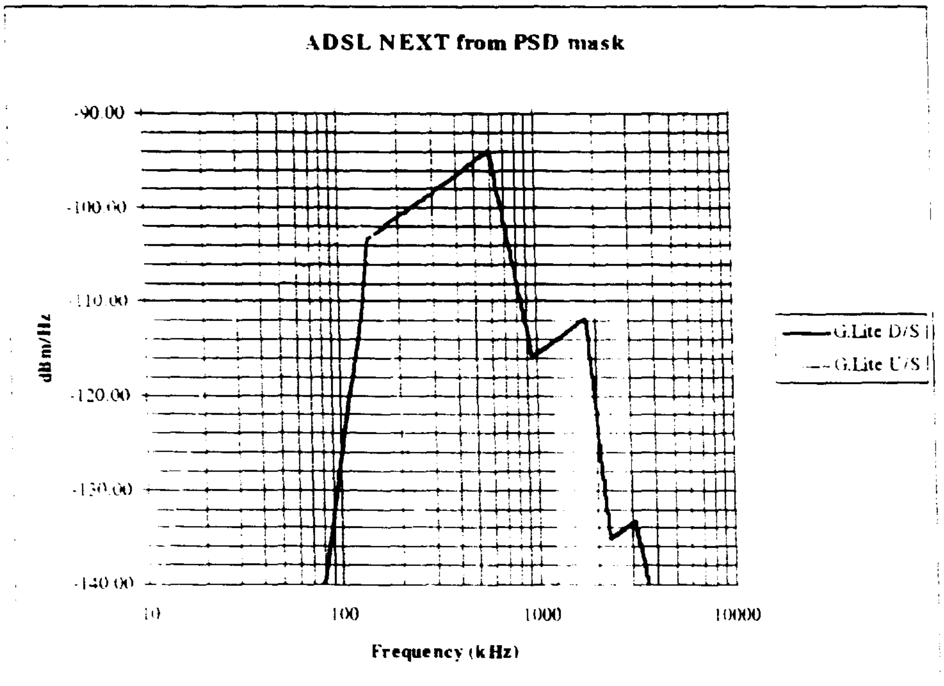

Figure 10 - NEXT for G.992.2 (G.lite) FDD PSD

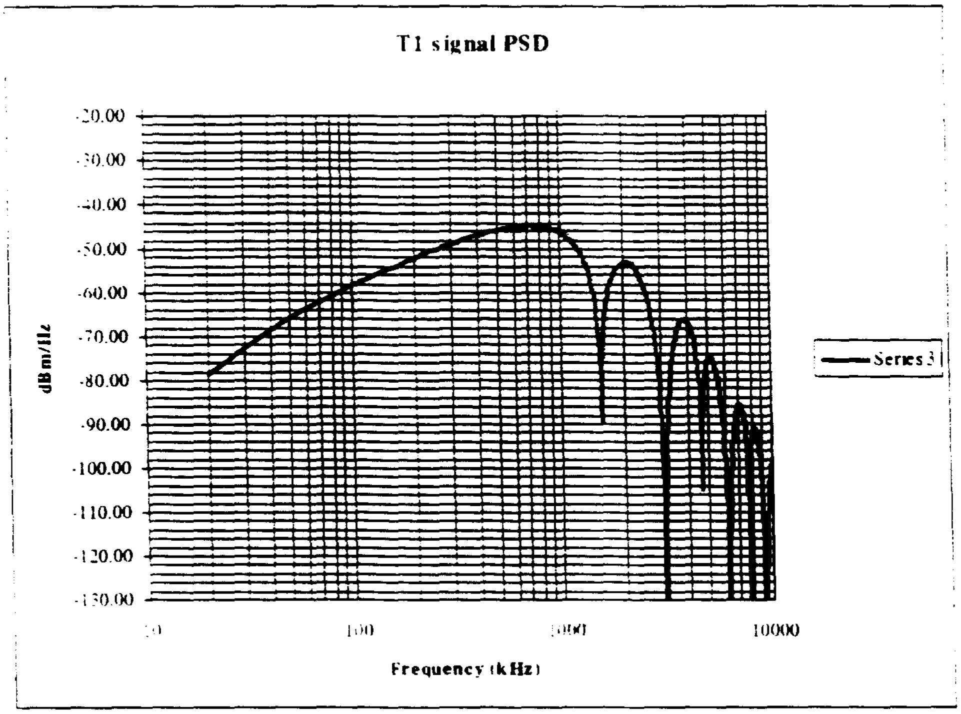

Figure 11 – T1 Tx PSD

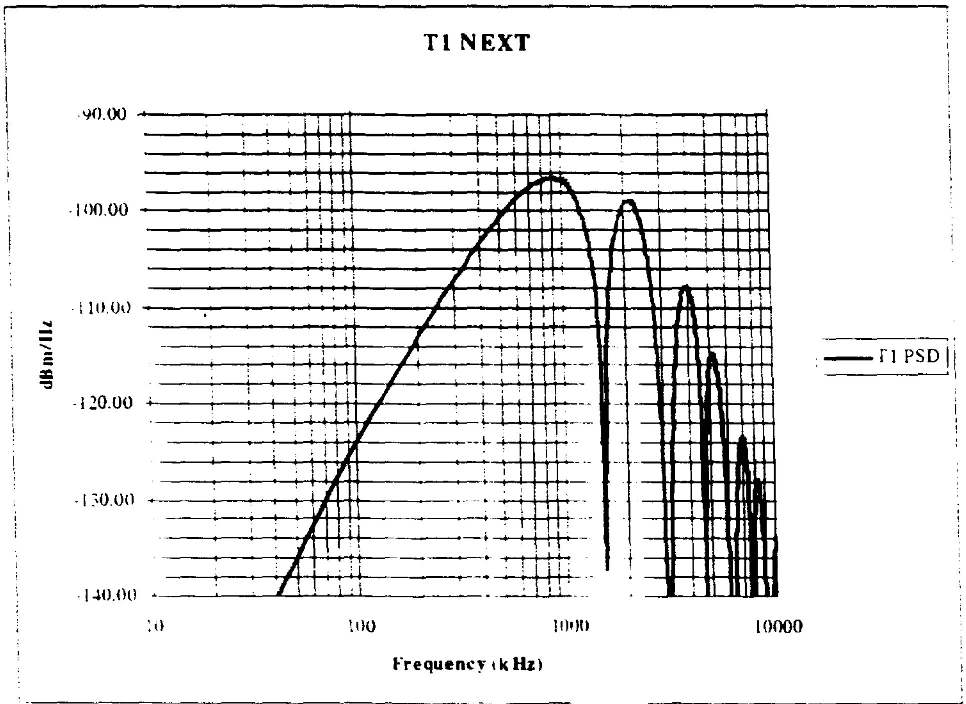

Figure 12 - NEXT T1 Tx PSD

Receiver Models for Standard xDSL Systems

Models for the performance of the following standard xDSL systems are described here :

1. ISDN
2. HDSL
3. T1.413issue2 non-overlapping spectra full-rate DMT ADSL:
   - US and DS
4. G.992.2 (G.lite) non-overlapping 'splitterless' DMT ADSL
   - US and DS
   - On-hook and off-hook parallel telephone at CPE end
5. T1

In each case, a reference receiver model is defined that permits assessment of the impact of crosstalk noise on the performance of that standard xDSL system.

For the fixed-rate xDSL services – ISDN, HDSL and T1 – the performance of the system is expressed in terms of excess noise margin to achieve a target bit-error-rate of 10^{-7}. A negative margin indicates that the service would be unavailable on some loops: 6dB margin is considered desirable to provide the service. The margins are calculated on both upstream (US: CPE->CO) and downstream (DS: CO->CPE) directions to reflect the different crosstalk noise PSDs that may exist at each end of the loop.

For rate-adaptive xDSL services (ADSL) the xDSL performance, in the presence of crosstalk, is expressed in terms of the capacity (attainable data rate), for a specified minimum noise margin and target bit-error-rate of 10^{-7}. Where the crosstalk noise is particularly severe, the service will be unavailable on some loops; in less severe, but still significant cases, the capacity will be significantly below that obtainable with better management of the types of other xDSL systems in the same binder. In setting standards for spectral compatibility of new xDSL technologies, it is important to discriminate between claims of spectral compatibility which implicitly accept significant degradations in the capacity of rate-adaptive systems due to legacy system technologies and those based on actually minimizing reductions in capacity.

ISDN receiver model

The ISDN baseband 2B1Q receiver model assumes:

- a background, additive white Gaussian noise component with PSD of −140dBm/Hz
  - in practice, since ISDN and HDSL receivers are designed with the expectation of significant NEXT, the inherent receiver noise floor will be much higher than this; the consequence of using a lower noise floor is to over-estimate the noise margin in cases of few disturbers.

- an 8/64 baud spaced DFE (decision feedback equalizer) with residual inter-symbol interference (ISI) below the receiver noise floor

- a second order Butterworth low-pass receive filter with f_{3dB} at 80kHz.

HDSL receiver model

The HDSL baseband 2B1Q receiver model assumes:

- a background, additive white Gaussian noise component with PSD of −140dBm/Hz
  - in practice, since ISDN and HDSL receivers are designed with the expectation of significant NEXT, the inherent receiver noise floor will be much higher than this; the consequence of using a lower noise floor is to over-estimate the noise margin on cases of few disturbers.

- an 8/64 baud spaced DFE (decision feedback equalizer) with residual inter-symbol interference (ISI) below the receiver noise floor

- a fourth order Butterworth low-pass receive filter with f_{3dB} at 196kHz.

T1 receiver model

T1 systems do not support bridged taps and typically use only a linear equalizer. Simulations with a pure linear equalizer should be used. The excess margin over the 10^{-7} BER level can be used as a comparative number.

Because T1 is NEXT limited, the receiver noise will typically be much higher than -140 dBm/Hz, so results with AWGN only will be greatly over-estimated by using that noise level.

T1.413issue 2 (non-overlapped spectra) full-rate DMT ADSL receiver model

The receiver model for the full-rate DMT ADSL receiver has the following characteristics:

- noise margin of 6dB, with a coding gain of 3dB
- the user data rate is given by the raw capacity less 10% (32kbps minimum) for forward-error-correction (FEC) overhead and 32kbps for framing and signaling channels (EOC/AOC/...)
  - note that this suggests a minimum raw data rate of 96kbps is required to maintain service (at a user data rate of 32kbps)
- a separation of 7 carrier spacings (~30kHz) is assumed between upstream and downstream frequency bands to allow for the implementation of realistic upstream/downstream band-splitting filters at the transmitter and receiver DMT ADSL receivers
- a background AWGN noise PSD of −140dBm/Hz
- constellation sizes of up to 15 bits/carrier
  mis-equalization and timing jitter effects are assumed to be below the noise floor

G.992.2 Splitterless DMT ADSL Receiver Model

The (G.lite) 'splitterless' DMT ADSL receiver model is much like the full-rate version, less the added downstream carriers. Its characteristics are:

- noise margin of 4dB, with a coding gain of 3dB
- the user data rate is given by the raw capacity less 10% (32kbps minimum) for forward-error-correction (FEC) overhead and 32kbps for framing and signaling channels (EOC/AOC)
  - note that this suggests a minimum raw data rate of 96kbps is required to maintain service (at a user data rate of 32kbps)
- a separation of 7 carrier spacings (~30kHz) is assumed between upstream and downstream frequency bands to allow for the implementation of realistic upstream/downstream band-splitting filters at the transmitter and receiver DMT ADSL receivers
- a background AWGN noise PSD of −140dBm/Hz
- constellation sizes of up to 8 bits/carrier
  - G.992.2 permits higher order constellations, but requires only 8 bits/carrier
- mis-equalization and timing jitter effects are assumed to be below the noise floor

NOTE: Operation of G.992.2 CPE with parallel off-hook telephone sets is a design objective that is not considered here. Operation in the 'off-hook' state is hindered by the need for power cutback at the upstream transmitter to mitigate telephone/modem interactions. While this will exacerbate the negative impact of crosstalk noise on upstream capacity in this state. this is as much a G.992.2 design issue. as it is a spectral compatibility issue and is not treated here.

Performance of Standard xDSL systems in the Presence of Disturbers

With the models and formulae discussed above, it is now possible to examine the impact of disturbers with defined Tx PSD masks on standard xDSL systems in the loop plant.

Consistent with the xDSL deployment scenarios discussed earlier, we consider the following xDSL systems and operating loop lengths :

1. ISDN on 15kft 26AWG
2. HDSL on 9kft 26AWG
3. T1 on 5.28kft 26AWG
4. T1.413 full-rate on 9kft 26AWG
5. G.992.2 (G.lite) on 9kft 26AWG
6. G.992.2 (G.lite) on 15kft 26AWG

... in the absence of crosstalk, and with crosstalk from N = 1, 2, 5, 10, 24 or 49 xDSL disturbers.

The transmit PSDs of the xDSL disturbers correspond to the following PSDs :

A. ISDN Tx PSD
B. T1.601 mask
C. HDSL Tx PSD
D. T1.413issue2 (non-overlapping spectra) mask
   (denoted 'T1.413-FDD-mask')
   - Only downstream mask differs from 'G.992.2 FDD mask' below
E. T1 Tx PSD
G. G.992.2 (G.lite) (non-overlapping spectra) masks
   (denoted 'G.992.2 FDD mask')
   - Separate upstream and downstream masks

ISDN service on 15kft 26AWG loop

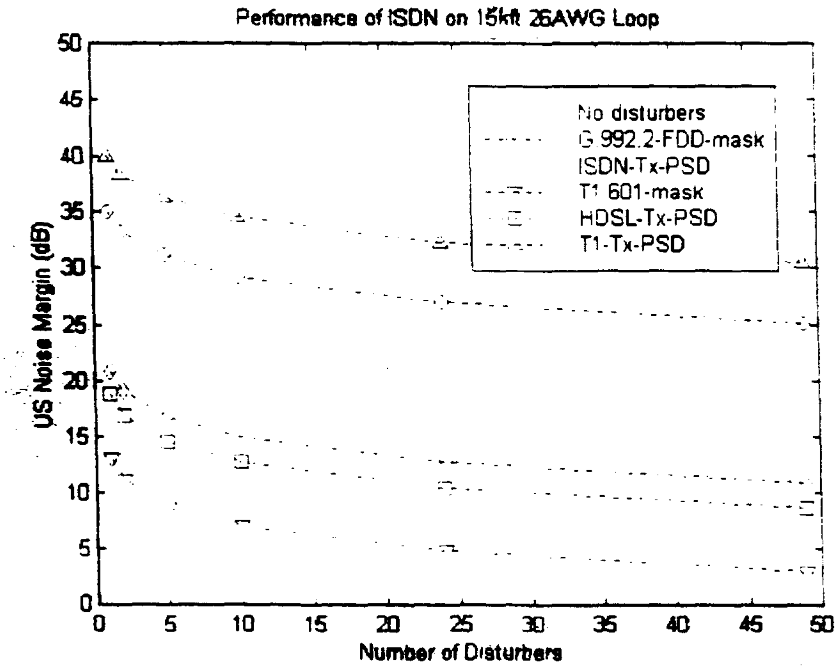

Figure 13 - ISDN US Noise Margin vs. Number/Type of Disturbers

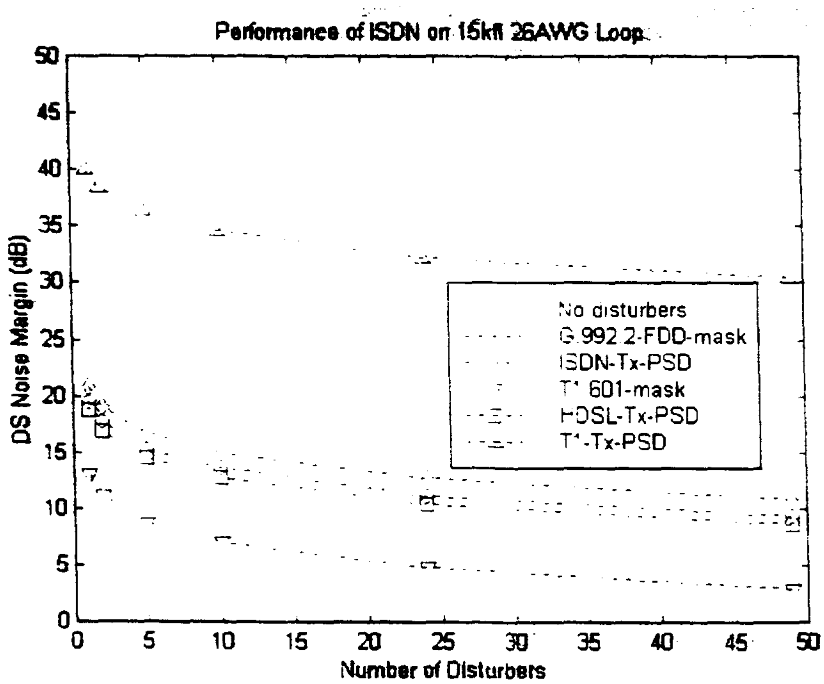

Figure 14 - ISDN DS Noise Margin vs. Number/Type of Disturbers

Key points:

1) The upstream margin is not affected by crosstalk from G.992.2 FDD-mask[12] compliant technologies in the same binder group.
2) In the downstream direction, the margin remains positive (not service-affecting) and the reduction due to G.992.2-FDD-mask-compliant disturbers is similar to that which would occur with ISDN disturbers (self -NEXT)
3) Disturbers with a Tx PSD equivalent to the T.601 PSD mask have a much larger impact on noise margin than a true ISDN signal PSD

[12] The full-rate T1.413-FDD mask has the same impact on ISDN as the G.992.2 (G.lite) FDD mask

HDSL service margin on 9kft loop

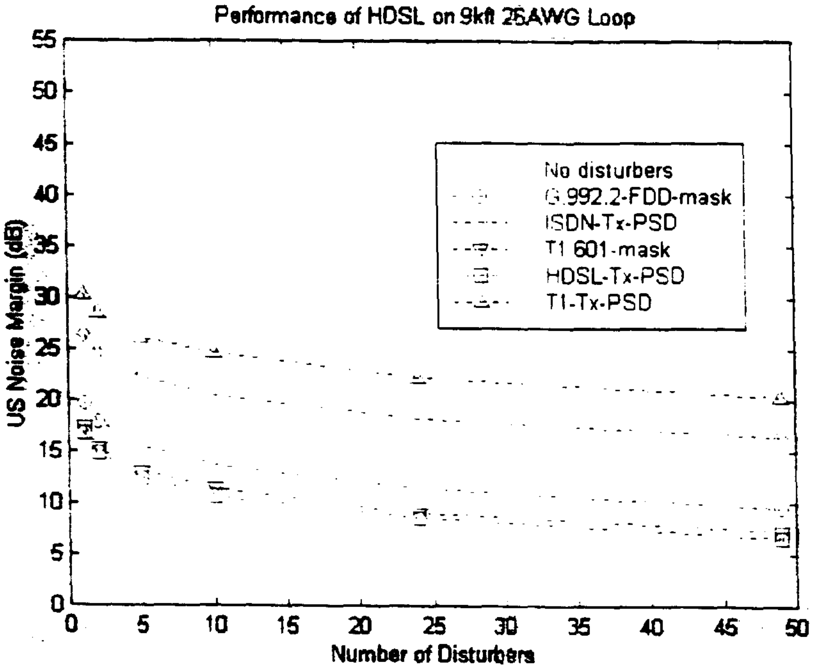

Figure 15 - HDSL US Noise Margin vs. Number/Type of Disturbers

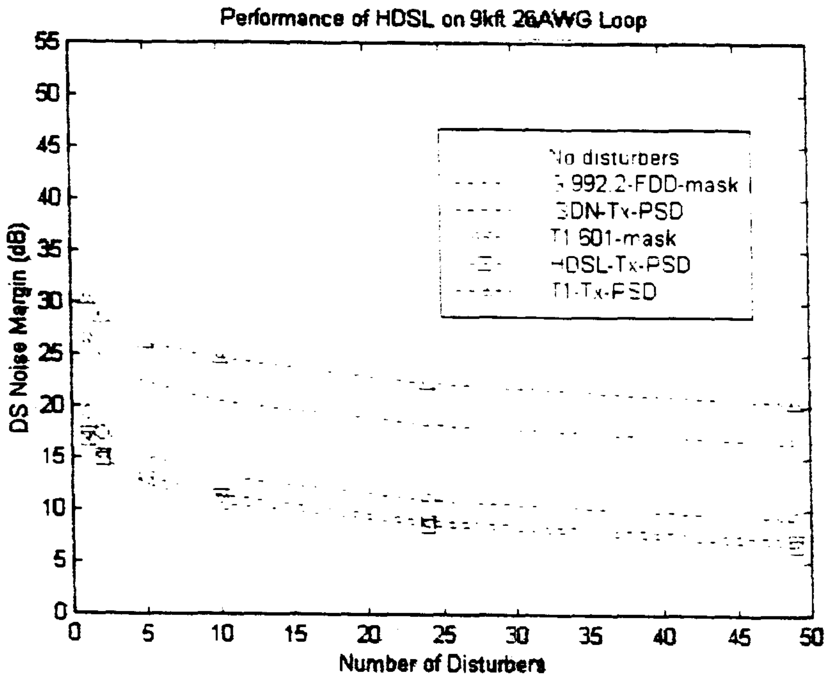

Figure 16 - HDSL DS Noise Margin vs. Number/Type of Disturbers

Key points:

1) In both directions, the margin remains positive (not service-affecting) and the reduction due to G.992.2-compliant disturbers[13] is less than that which would occur with HDSL disturbers (self -NEXT)
2) Disturbers with a Tx PSD equivalent to the T.601 PSD mask have a much larger impact on noise margin than a true ISDN signal PSD

[13] The full-rate T1.413 FDD mask has the same impact on HDSL as the G.992.2 FDD mask

T1.413iss2 full-rate ADSL service

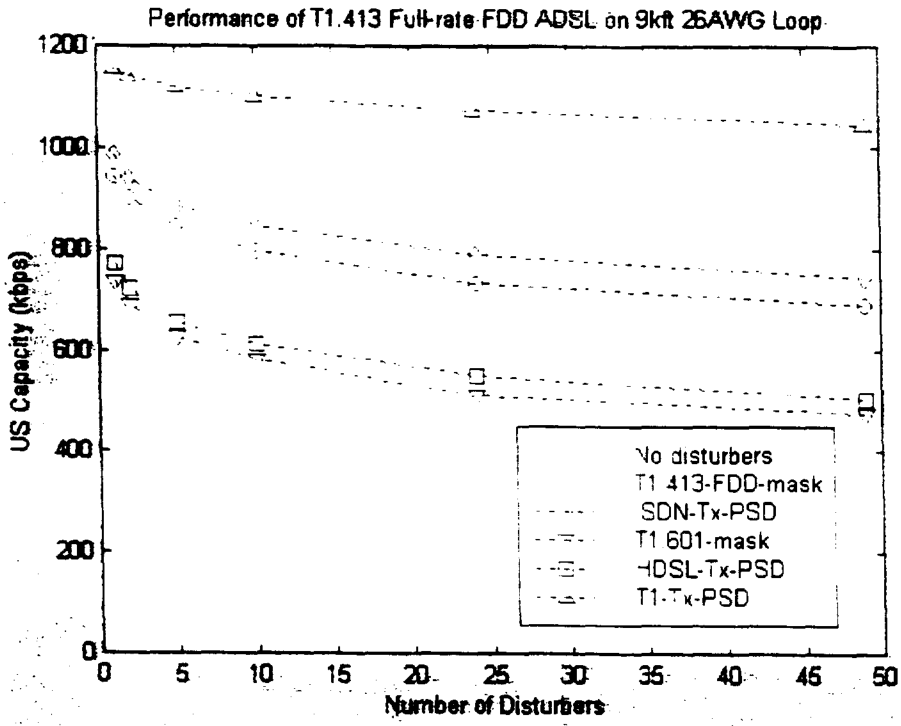

Figure 17 –Raw upstream capacity on 9kft loop

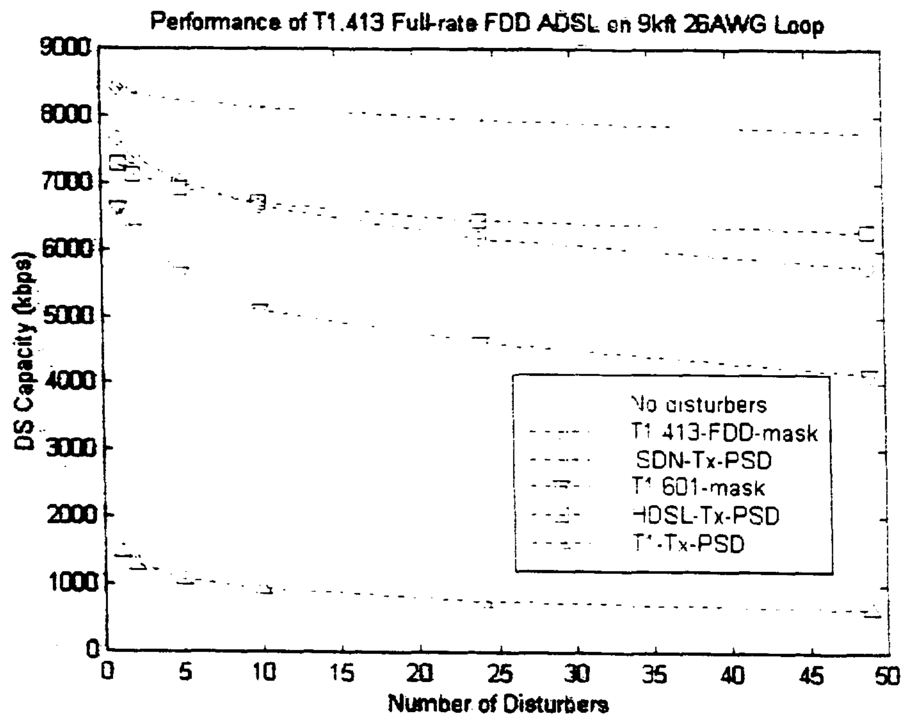

Figure 18 –Raw downstream capacity on 9kft loop

Key Points:

1. Upstream capacity significantly reduced by NEXT from other xDSL systems
2. Disturber Tx PSDs matching T1.601-mask are most harmful followed by those with HDSL-Tx-PSD
3. Downstream capacity is significantly reduced by NEXT from other xDSL systems (in order of 'harm' - T1 then T1.601-mask)
4. Disturbers with a T1-Tx-PSD drop capacity by ~85% vs. crosstalk from other T1.413 FDD xDSL systems

T1 service on 5.28kft loop

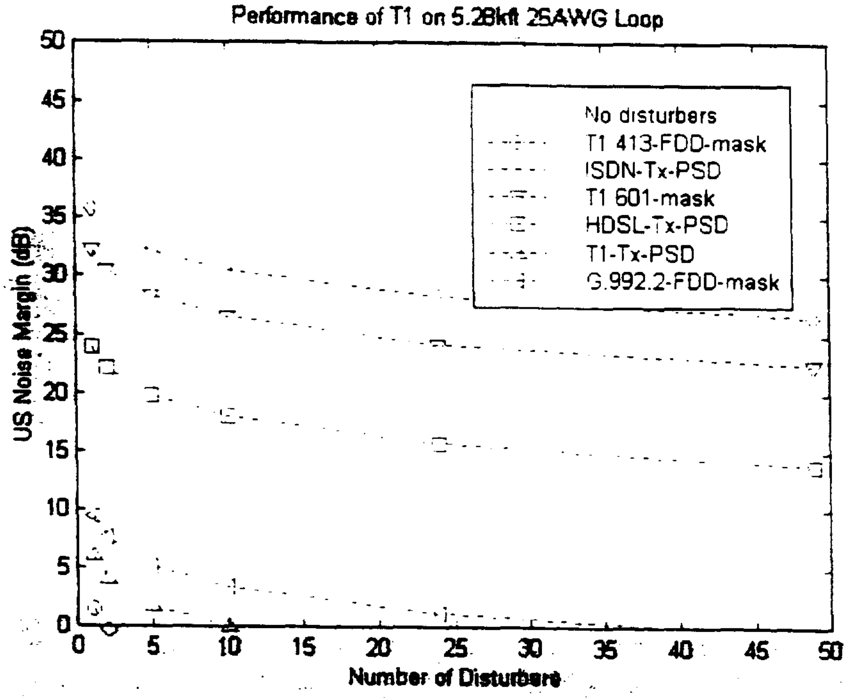

Figure 19 –Upstream T1 noise margin

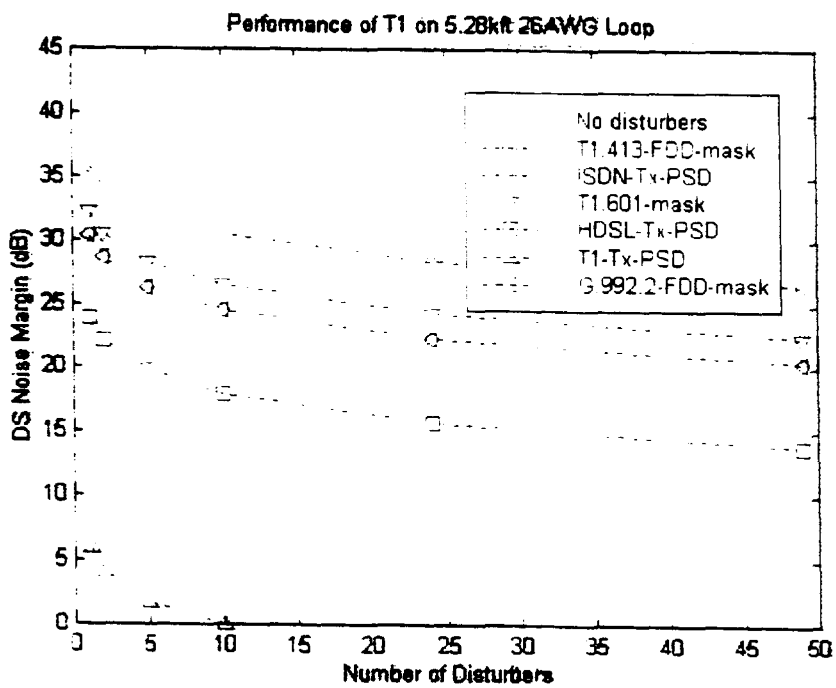

Figure 20 –Downstream T1 noise margin

Key Points:

1. The downstream margin is not affected by NEXT from any of the xDSL systems considered
2. In the upstream direction, margins are below or close to zero in presence of an T1.413-FDD mask disturber --> some pairs will not support service
3. T1s per binder group also limited by self-NEXT between T1 systems in both directions. For this reason, it is recommended that T1 systems use separate binder groups for each direction of transmission.
4. In the upstream direction, margins under G.992.2 FDD mask are better than under the same number of T1 disturbers (self-NEXT)

G.992.2 (FDD) ADSL service on 9 and 15kft loops

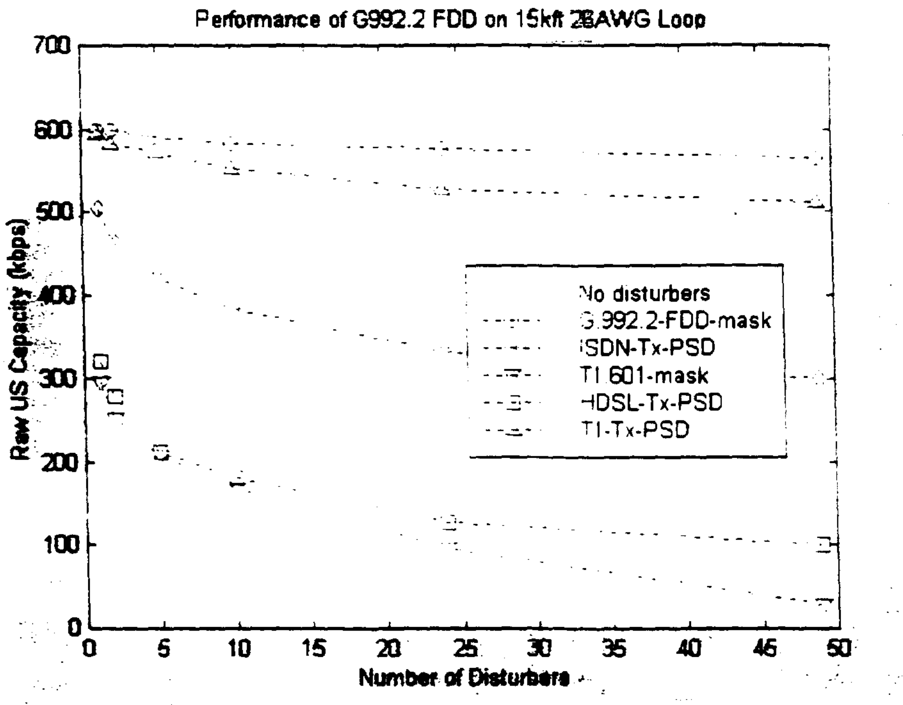

Figure 21 - Raw Upstream Capacity on 15kft 26AWG loop

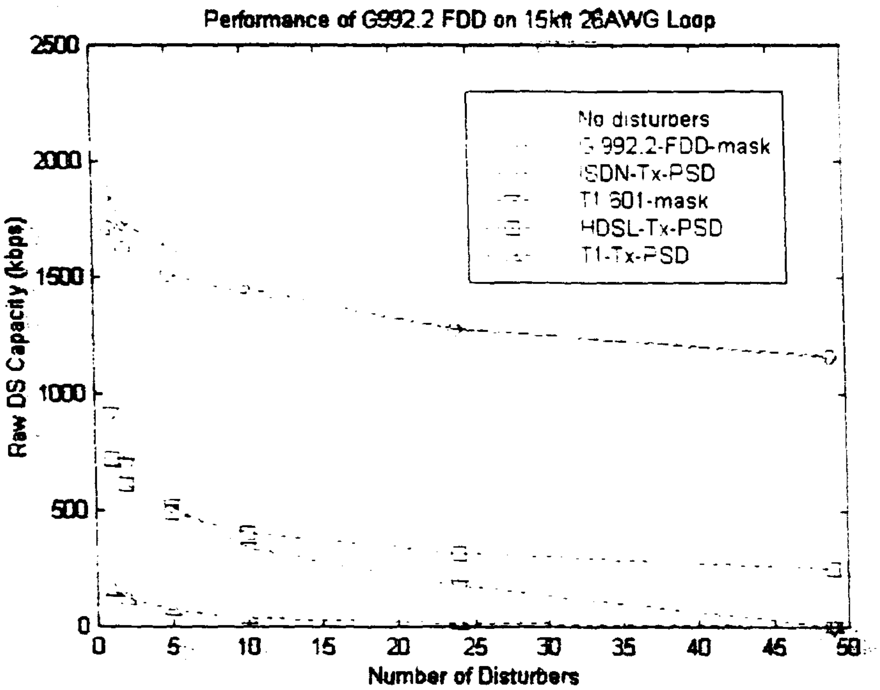

Figure 22 - Raw Downstream Capacity on 15kft 26AWG loop

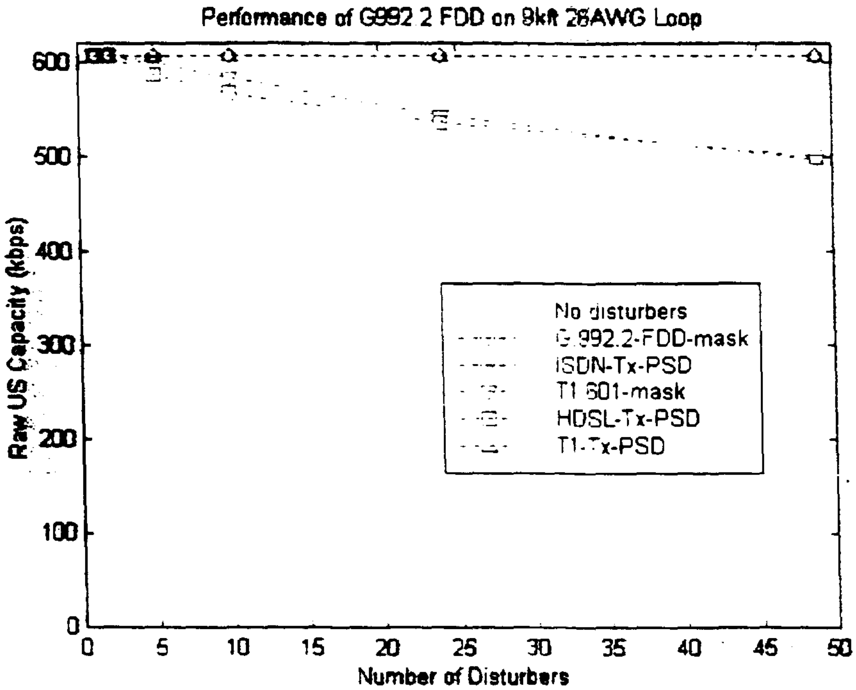

Figure 23 - Raw G.992.2 Upstream Capacity on 9kft loop

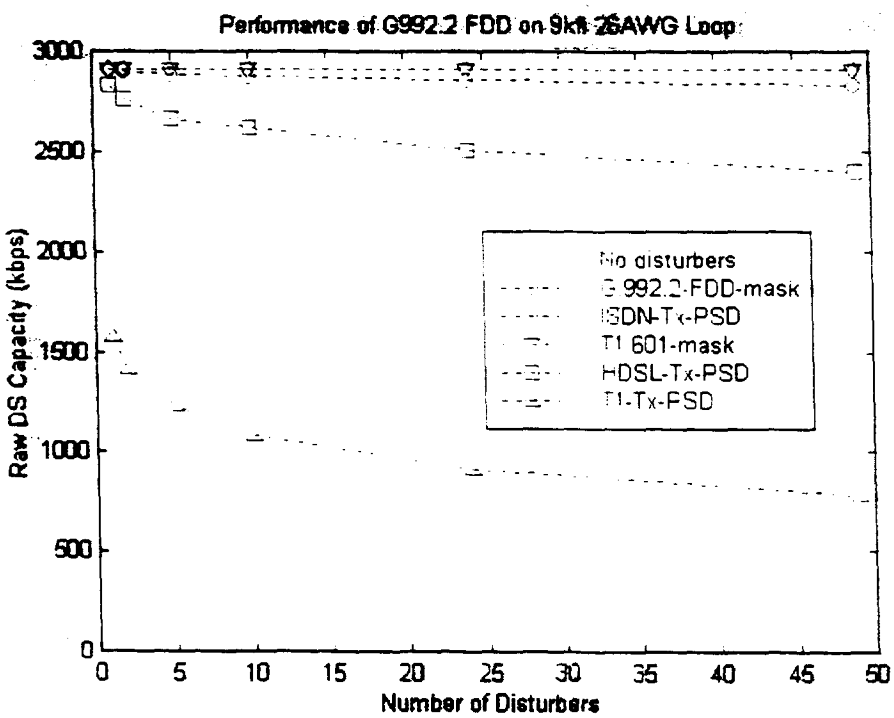

Figure 24 - RawG.992.2 Downstream Capacity on 9kft loop

Key Points:

1. On long loops, upstream capacity is significantly reduced in the presence of NEXT from disturbers transmitting in the same frequency range as the upstream G.992.2 receiver. xDSLs with T1.601-mask defined Tx PSDs cause the largest rate reduction, preventing delivery of *any* service in some cases; HDSL is almost as bad; ISDN results in significant capacity losses but won't prevent service.

2. Similarily, in the downstream direction, even 1-2 disturbers with T1-Tx-PSDs will disrupt service, while HDSL- and T1.601-mask-like disturbers significantly impact capacity.
   - The reasons behind the large drop in capacity due to disturbers meeting the T1.601-mask and those meeting a mask defined by the actual ISDN Tx PSD are apparent from figures ? and ?. The discrete multi-tone (DMT) modulation scheme of standard (T1.413 and G.992.2) ADSL is able to exploit the nulls (at multiples of the ISDN baud rate) in the ISDN Tx PSD, to increase capacity. This is not possible where the disturber PSD corresponds to the T1.601 mask.

3. On CSA loops (< 9kft 26AWG) only T1-Tx-PSD disturbers have a severe impact on capacity. With the 8 bit/carrier maximum constellation size set for the reference G.992.2 splitterless DMT ADSL receiver, the crosstalk noise from other xDSL disturber PSDs has little impact.

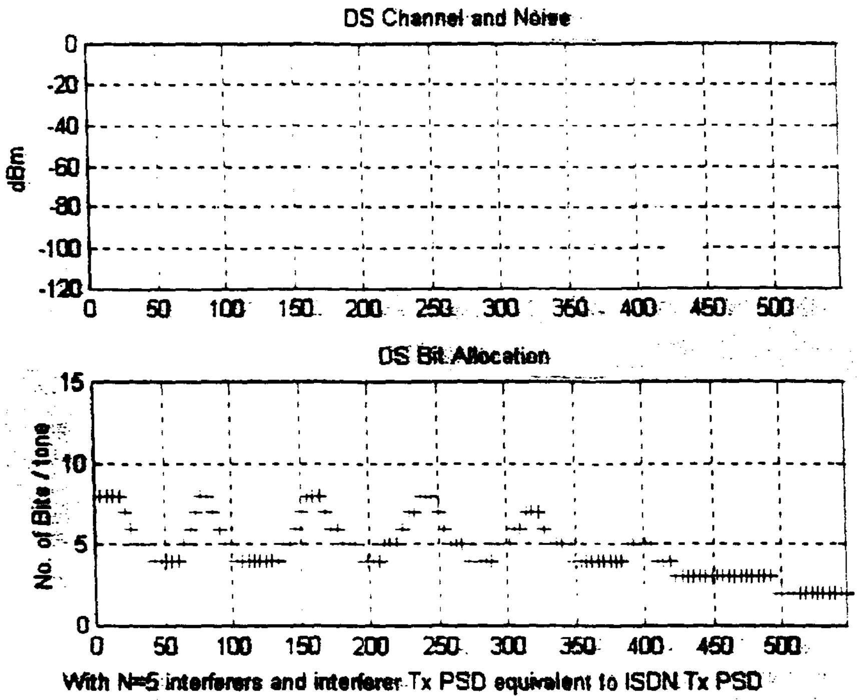

Figure 25 - Bit allocation with Disturbers meeting ISDN Tx PSD

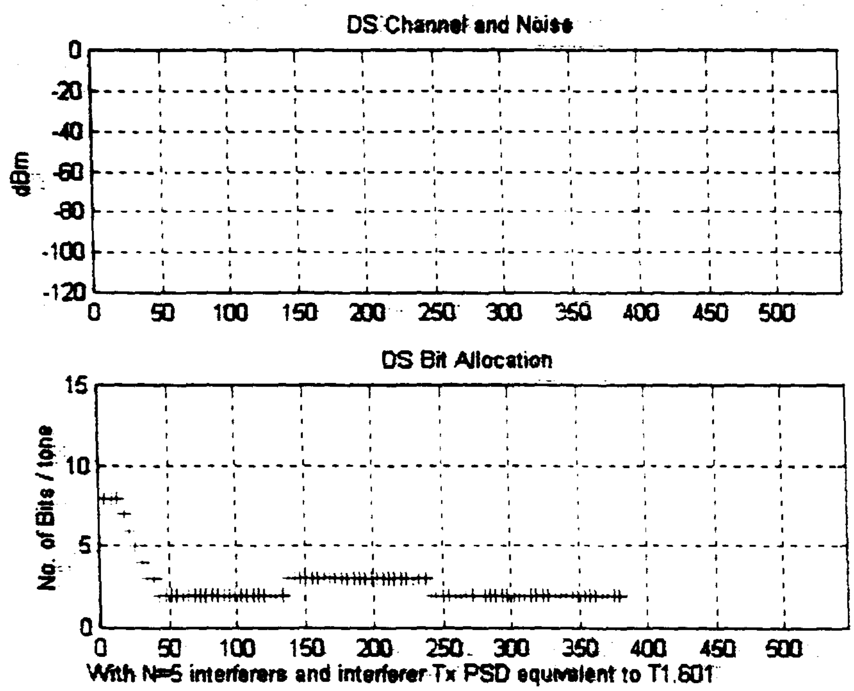

Figure 26 - Bit allocation with Disturbers matching T1.601 PSD mask

Guidelines on Spectrum Management

A number of guidelines for effective management of the loop plant may be developed from the information rising from the xDSL system spectral compatibility benchmarks.

1) xDSL systems with transmit PSDs conforming to G.992.2 (G.lite) non-overlapped PSD mask should be considered spectrally compatible with existing and emerging xDSL services
   - their impact on other systems in the binder group is comparable or less than that due to self-NEXT amongst those DSL systems

2) xDSL systems with transmit PSDs conforming to T1.413issue2 non-overlapped PSD mask should be considered spectrally compatible with existing and emerging xDSL services, with the exception of T1 lines which should be segregated in a different binder group

3) New xDSL systems that do not meet the G.992.2 (G.lite) non-overlapped PSD mask can still be considered spectrally compatible where the vendor provides evidence of its compatibility using methods comparable to those outlined here.
   - standardization of these methods – in T1E1 – can accelerate the introduction of future, innovative xDSL systems

4) Though not as spectrally-'friendly' as G.992.2 (G.lite)-compliant DSLs, HDSL or ISDN may be safely deployed in the same binder group as other DSL systems, where the loops in that binder group are shorter than than 9kft (CSA).
   - when spectrally-friendlier alternatives, that meet the service characteristics of ISDN and HDSL , become available, they will be preferred over these NEXT - limited systems

5) A limited number of ISDN DSL systems may be accommodated in the same binder group as T1.413-mask compliant FDD ADSL systems, without severe impacts on the capacity of those ADSL systems
   - there are capacity losses: but these may be considered acceptable alternatives to the cost of re-engineering binder groups with legacy ISDN services

6) Conformance to the T1.601 worst-case PSD mask is not recommended as a useful measure of spectral-compatibility.
   - The negative impact of disturbers matching this Transmit PSD is greater than that of actual ISDN DSL systems, whose transmit PSDs fall significantly below the T1.601 mask at frequencies which are at multiple of the ISDN baud rate.

7) T1 should not be placed in the same binder group as ADSL.

8) Systems with excess margin (fixed-rate) or capacity (rate-adaptive) should reduce their transmit power wherever possible to minimize crosstalk into adjacent systems.

Response to questions from the FCC

The replies to the individual questions draw from the material presented above.

1. **What interim rules for xDSL should be established such that any equipment meeting these at the CO can be connected to unbundled loops with reasonable confidence that technology will not significantly degrade other services?**

   As per guidelines above.

2. **How might existing technical standards be used to facilitate an interim standard?**

   The existing G.992.2 and T1.413 (non-overlapped spectra) Tx PSD mask and masks corresponding to ISDN and HDSL transmit signals, as described in [T1.413], may be used to establish compatibility, , with some constraints as outlined in the preceding recommendations (see guidelines 1 & 3).

   Similarily new xDSL systems may be proven compatible by demonstrating that they do not cause harm to existing and impending standards-based xDSL systems, using an assessment methodology comparable to that outlined here.

3. **How can we ensure that such interim rules will not detrimentally affect future services?**

   A number of issues must be considered to avoid affecting future services:

   1. flexibility in rules to accommodate new technologies and technological advances

      - where the new technology can be demonstrated to avoid harm to existing services, using recognized evaluation methods, that technology, and the service it provides, should be permitted

   2. maintaining a clean spectral environment in the copper loop plant

      - the rules should discourage perpetuation of spectrally-'unfriendly' xDSL systems, by setting limits on legacy systems, that accommodate current penetrations levels but cap further deployment that would significantly hamper the performance of new systems
        - these limits should not be abused to introduce new xDSL systems with similarily 'unfriendly' Tx PSDs.

      - The rules should encourage development of new systems with the required service characteristics to replace the 'unfriendly' legacy systems, over time

Response to questions from the FCC

The replies to the individual questions draw from the material presented above.

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        - these limits should not be abused to introduce new xDSL systems with similarily 'unfriendly' Tx PSDs.

      - The rules should encourage development of new systems with the required service characteristics to replace the 'unfriendly' legacy systems, over time

- This will lead to an overall cleaning up of the loop plant spectral environment

4. How can compliance be ensured/enforced?

xDSL technologies that are shown to meet the G.992.2 non-overlapped spectra PSD masks would be considered compliant with the proposed interim standard. T1.413issue2 non-overlapped spectra PSD mask is also acceptable with the caveat that the system not share a binder group with T1.

xDSL technologies not meeting these PSD masks must be proven to avoid harm to other standard xDSL services in the loop plant using methods comparable to those outlined here. In particular, it must be shown to not impact service on long loops that will limit that service availability. This is particularly true where the candidate xDSL technology may be replaced by a proven spectrally compatible technology capable of delivering the same service.

Problems in the field that cannot[14] be resolved by the methods above, need to be dealt with using appropriate field diagnostic tools and methods.

5. Can there be one mask or set for all uses or should there be different masks depending on the technology or the operating environment?

Depending on loop lengths appearing in a binder group, single (long loops) or multiple masks (CSA loops) may be acceptable (see guidelines 1 & 3).

A single mask would be the long term objective, selected to maximize loop plant utilization across all providers and subscribers.

6. With regard to any interim standard, could the ILEC/CLEC agree to exceed them or is this a bad idea?

Permitting deployment of systems that exceed the standard should be permitted where the ILEC and CLEC(s) agree. We would, however, generally discourage the ILEC and CLEC(s) against such a strategy, on the basis of maximizing overall use of the loop plant through effective spectrum management.

Where an agreement to exceed the standard is made, that agreement should be public, the geographic region over which it applies should be stated clearly and it should be

[14] For example, this may be due to an otherwise acceptable xDSL system operating on pairs that have unusually poor longitudinal balance.

subject to a negotiated renewal on a regular basis to accommodate market and technology developments.

7. **If disputes arise, how should they be handled?**

Our preference is that the ILEC and CLEC(s) negotiate a solution, in a timely manner, based on :

- an agreed methodology – comparable to that outlined here - for assessing the impact of mixing xDSL technologies in the loop plant and
- a knowledge of the loop lengths and service mixes in binder groups

With rules based on recognized methods of xDSL system performance, and with knowledge of the loop plant (loop lengths) and the mix of xDSL systems deployed in specific binder groups (not at a per-pair basis), the basis for a negotiated resolution exists.

Strict definition of the exact method as part of a T1E1 recommended standard on Spectral Compatibility would also provide a basis for resolution of the dispute that all parties could acknowledge.

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FCC Ex Parte Meeting
Deployment of Wireline Services Offering Advanced Telecommunications Capability
CC: Docket No. 98-147

November 23, 1998

Spectral Compatibility of xDSL Technologies in the Copper Loop Plant

Outline

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- Introduction to methods for assessment of spectral compatibility of xDSL systems
- Key benchmarks of impact of xDSL interferer types on standard deployed and emerging xDSL systems
- Guidelines on xDSL system deployment in the loop plant
- Replies to questions posed by FCC on spectral compatibility rulings

Assessing Spectral Compatibility

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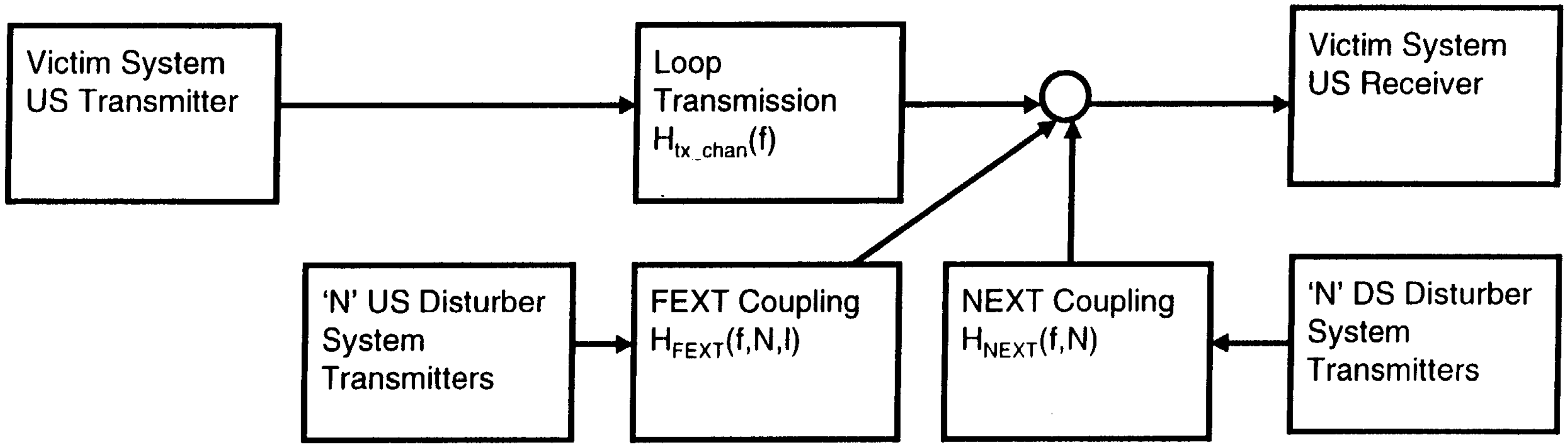
Based on

- standard methods for cable modeling
  - as concatenated two-port sections with parameters derived from RLGC primary cable constants
- scenarios for xDSL system deployment
  - e.g. HDSL for business users in CSA range; splitterless ADSL for residential users, with high loop coverage
- industry-standardized models for crosstalk coupling
  - with Nortel Networks extension for more realistic (less optimistic) far-end crosstalk (FEXT) configurations
- evaluation of standards-based PSD masks as candidates for rulings on spectral compatibility
- definition of standard deployed and emerging xDSL system receiver models for performance benchmarking
  - ISDN, HDSL, T1, full-rate (T1.413) FDD DMT ADSL, splitterless (G.992.2 (G.lite)) FDD DMT ADSL

Overall Model: Upstream Case



- **Victim systems use defined receiver models**
- **Disturber systems incorporate standard PSD masks for evaluation of their suitability as a measure of spectral compatibility**

Cable Loss vs. frequency

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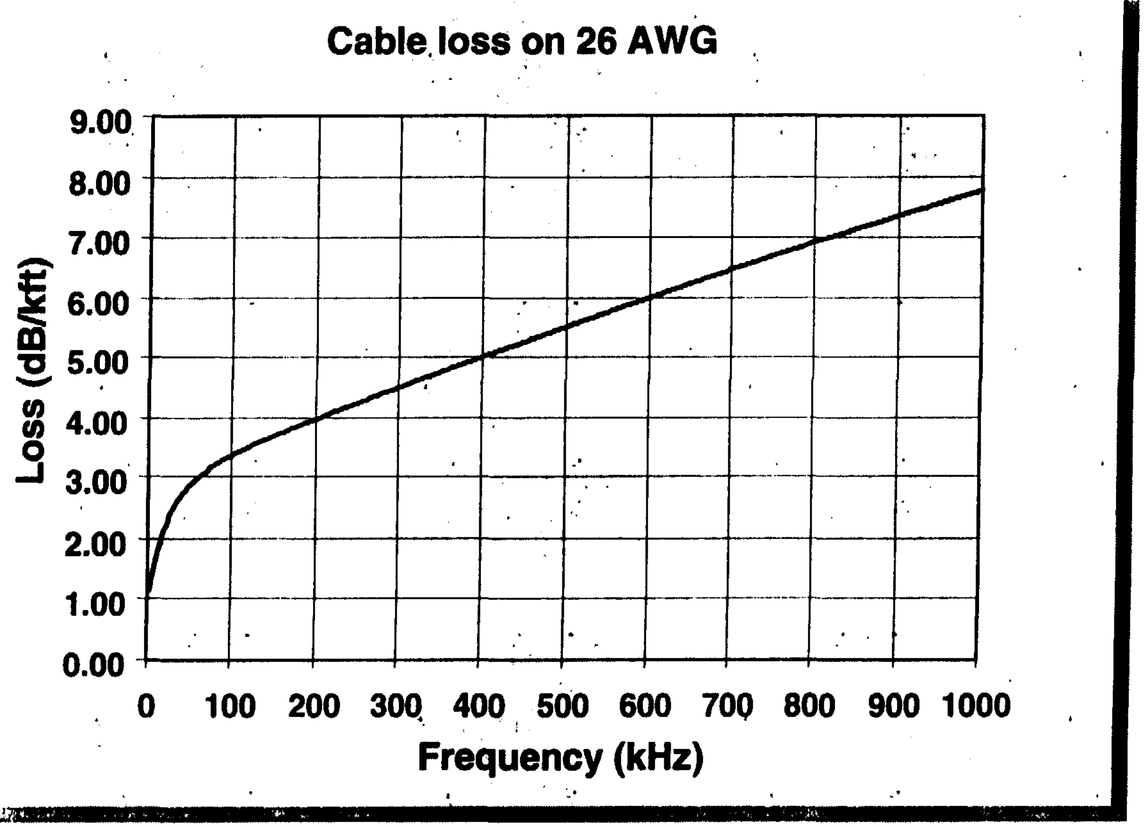

- **cable sections - including bridged taps - are modeled as two-port networks**
  - two-port I/O relationships are derived from published RLGC primary cable constants (for frequencies from 1Hz to 5MHz)

NEXT FEXT& Echo

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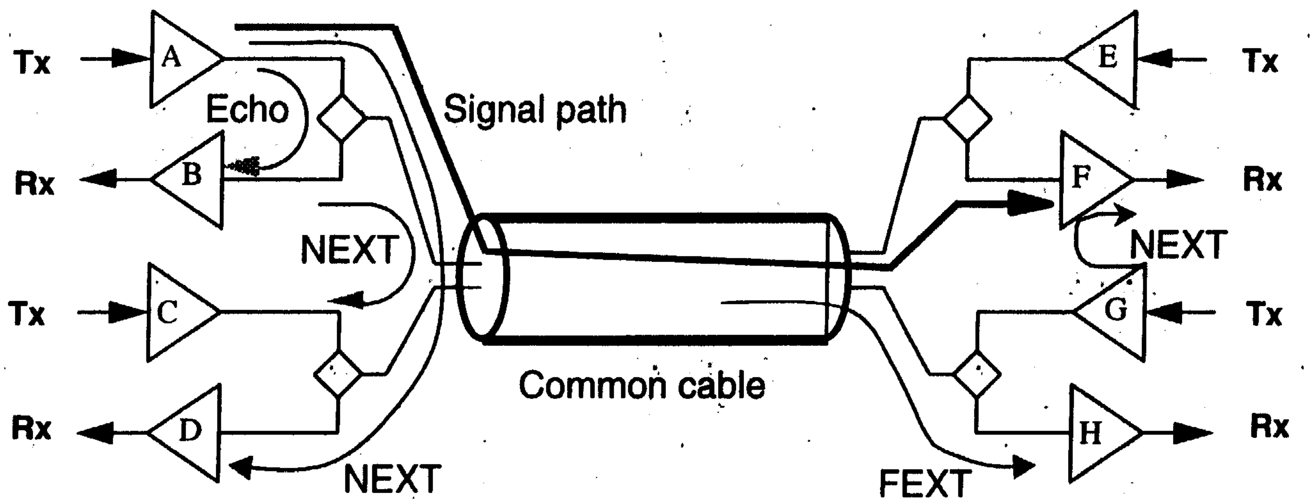


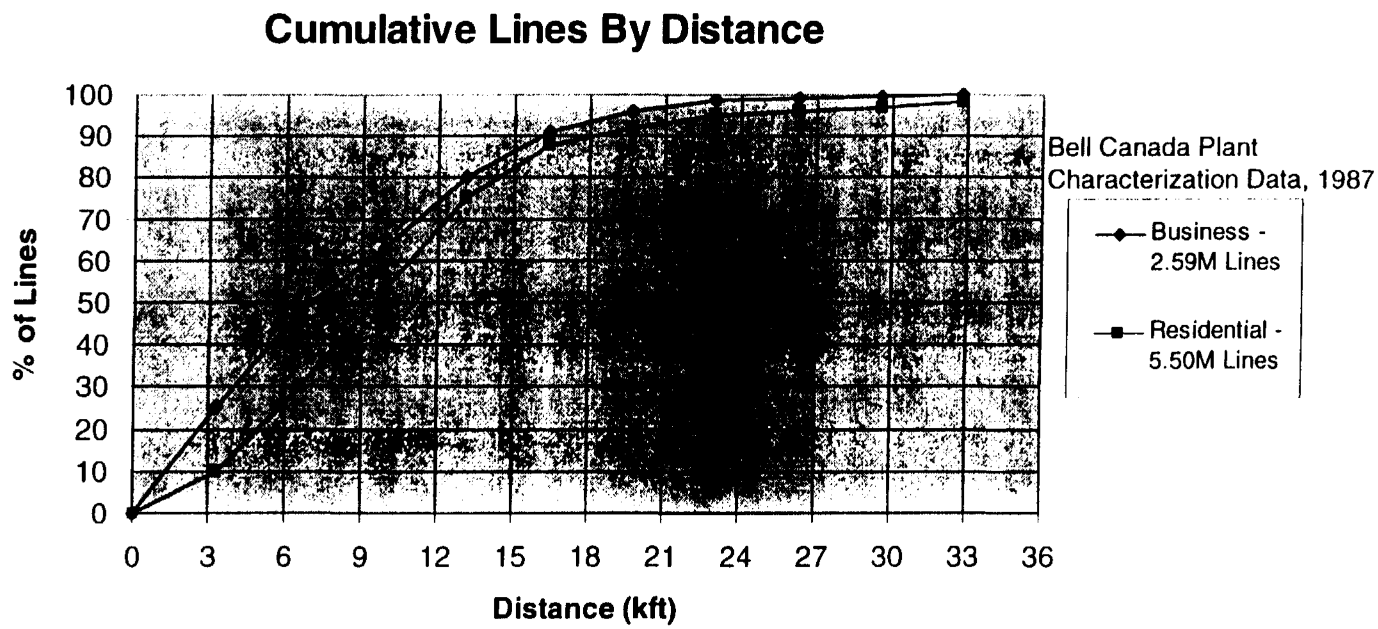
Signal path: Path over which the signal travels from the transmitter to the receiver.

Echo: Signal present at a receiver input and originating from the transmitter located on the same unit. It needs to be suppressed by trans-hybrid loss, filtering, or echo cancellation circuits.

NEXT: Near-End crosstalk, interference introduced by the coupling of output signals from co-located transmitters onto the pair used by the local receiver.

FEXT: Far-End crosstalk, interference introduced by the coupling of output signals from foreign transmitters onto the pair used by the local receiver.

Service Areas



Examine performance of

- T1, HDSL and full-rate ADSL systems over 9kft 26AWG loop (limit of CSA range)
- ISDN and splitterless ADSL to 15kft 26AWG (free of loading coils)
  - may also target longer loops with loading coils removed

Disturber PSD masks under study

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Examine PSDs which have been proposed* as sufficient to determine spectral compatibility with standard systems:

- ISDN signal PSD
- T1.601 mask
  - corresponds to the upper bound of PSD of signal from a [ISDN BRA] NT at interface
  - **NOT** the same as actual 'ISDN signal PSD'
- HDSL signal PSD
- T1 signal PSD
- T1.413issue2 (non-overlapped spectra) downstream mask
  - denoted 'T1.413 FDD mask' here.
- G.992.2 (G.Lite) (non-overlapping spectra) upstream and downstream masks
  - denoted 'G.992.2 FDD mask' here.

* T1E1.4/98-305; Paradyne waiver application

ISDN Tx PSD and T1.601 Mask

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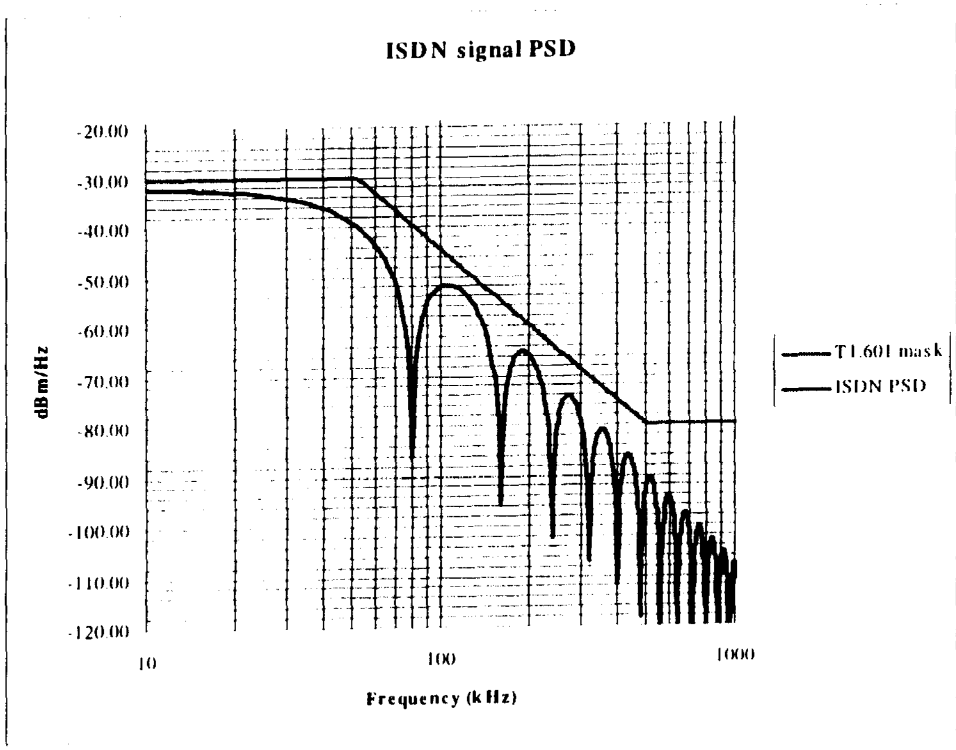

- **T1.601 mask often well-above actual ISDN Tx PSD**
- **A transmit signal matching the T1.601 PSD mask will exced the total transmit power limit in T1.601 (13.5+/-0.5dBm)**

ISDN Tx and T1.601 Mask NEXT PSDs

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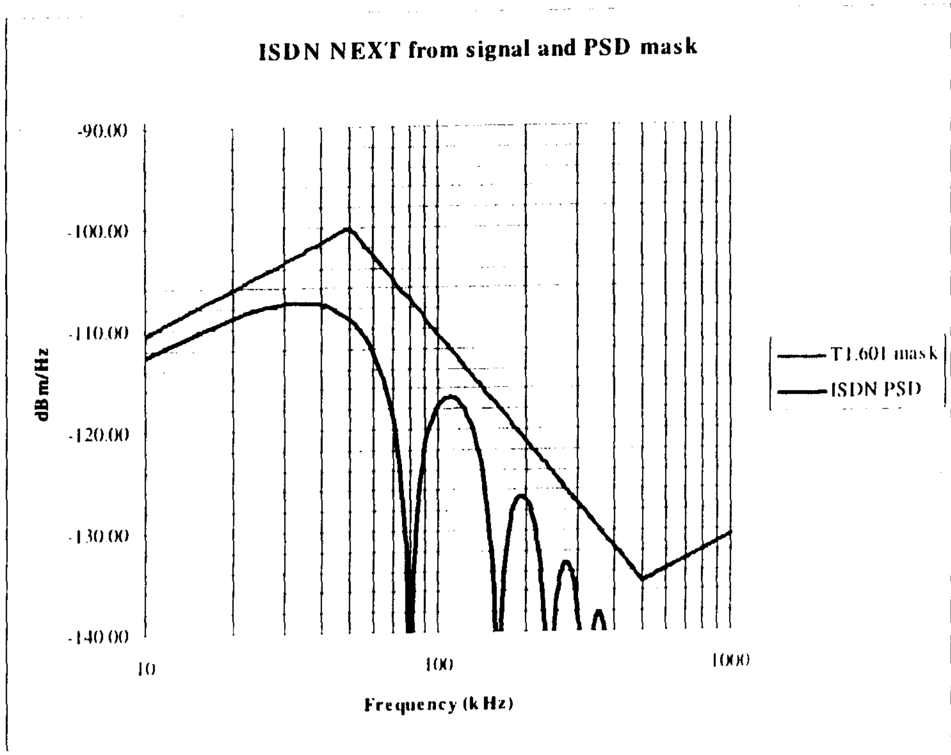

- **NEXT power concentrated in frequency band of ISDN, HDSL, and upstream T1.413 ADSL receivers**

HDSL Tx PSD NEXT

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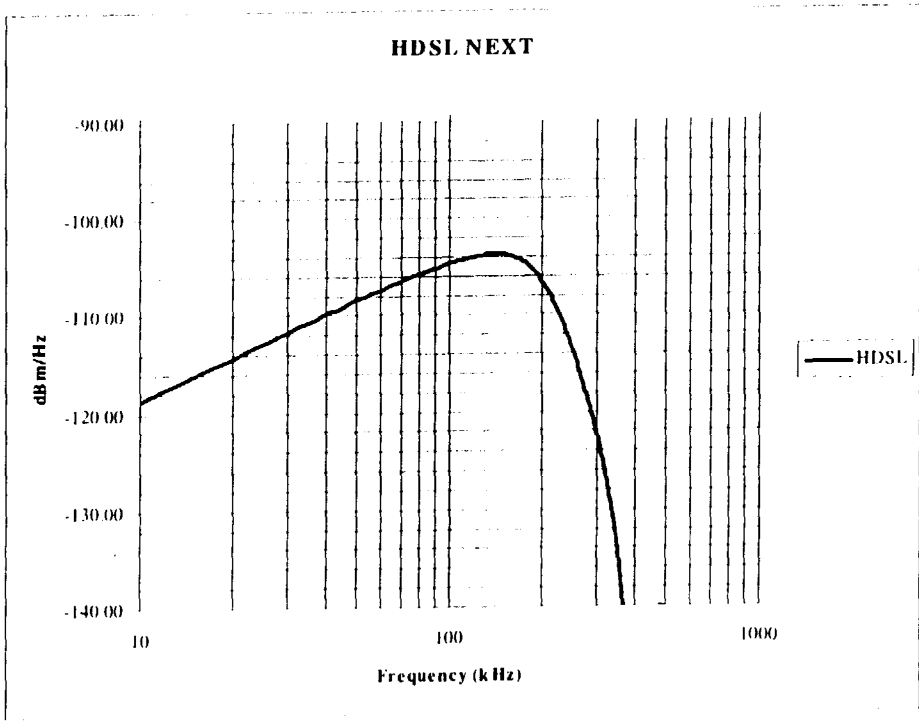

- **NEXT power concentrated in frequency band of ISDN, HDSL, and upstream T1.413 ADSL receivers**

T1.413 Mask NEXT PSD

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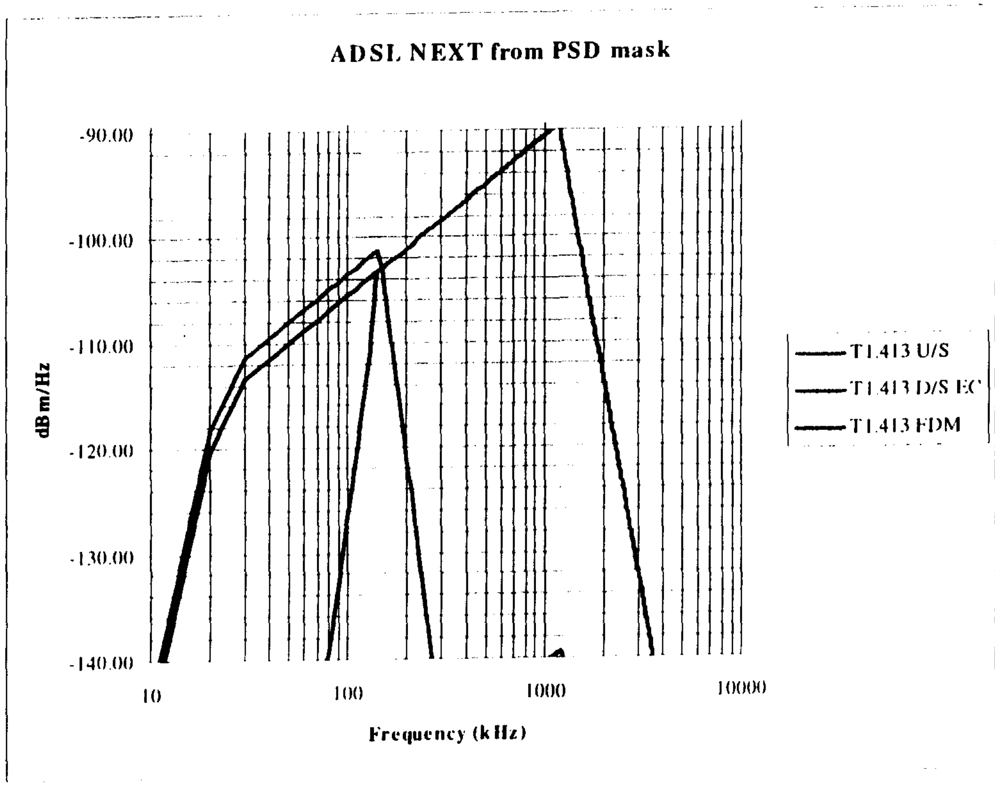
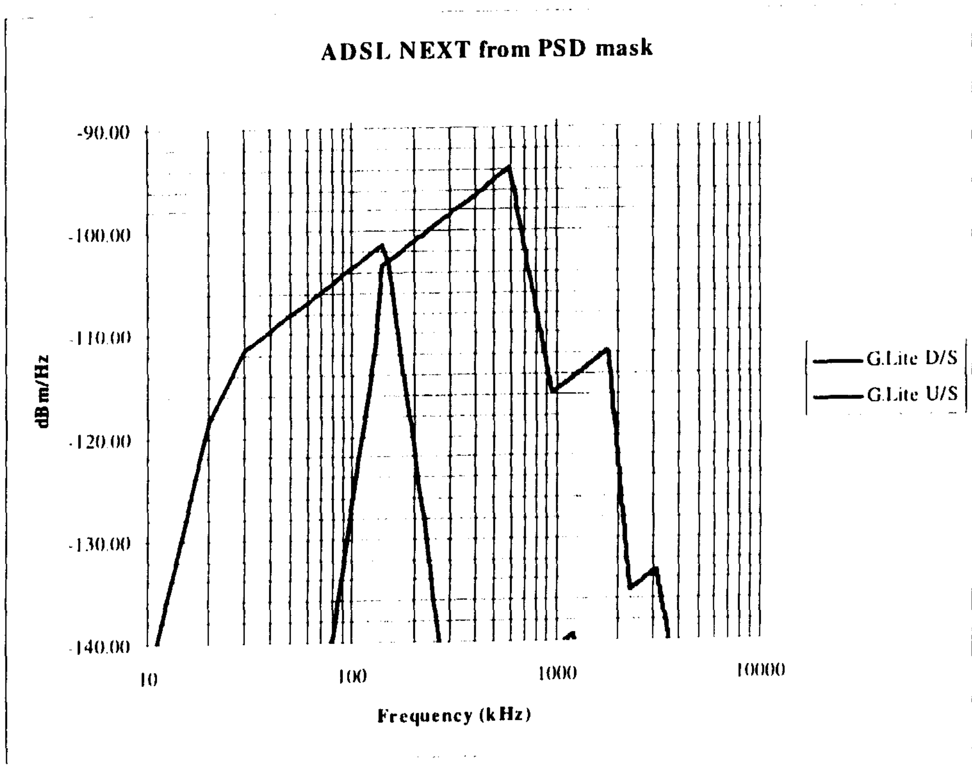


- **Upstream and downstream T1.413 FDD transmitters avoid frequency band used by adjacent loop, local end T1.413 (and G.lite) FDD receivers**

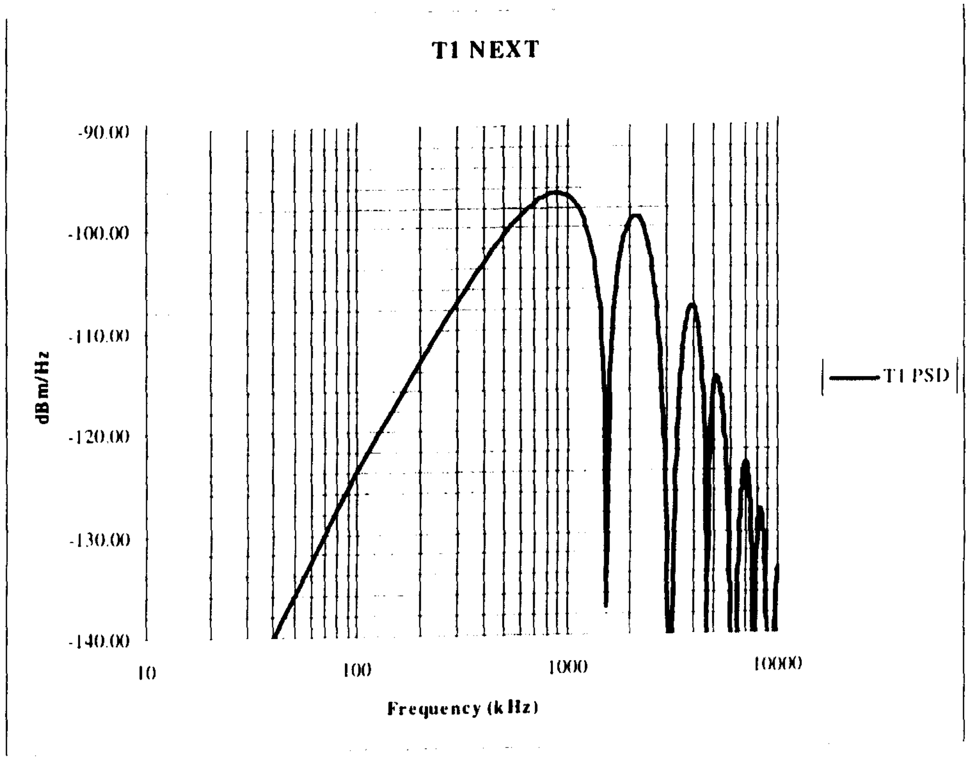
  ---> FEXT-, not NEXT-limited if all disturbers are also T1.413 FDD

G.992.2 (G.lite) Mask NEXT PSD



- **Upstream and downstream G.lite FDD transmitters avoid frequency band used by adjacent loop, local end T1.413 and G.lite FDD receivers**

T1 Tx NEXT PSD



- **NEXT power concentrated in frequency band of downstream T1.413 ADSL receivers**

Coupling Efficiency

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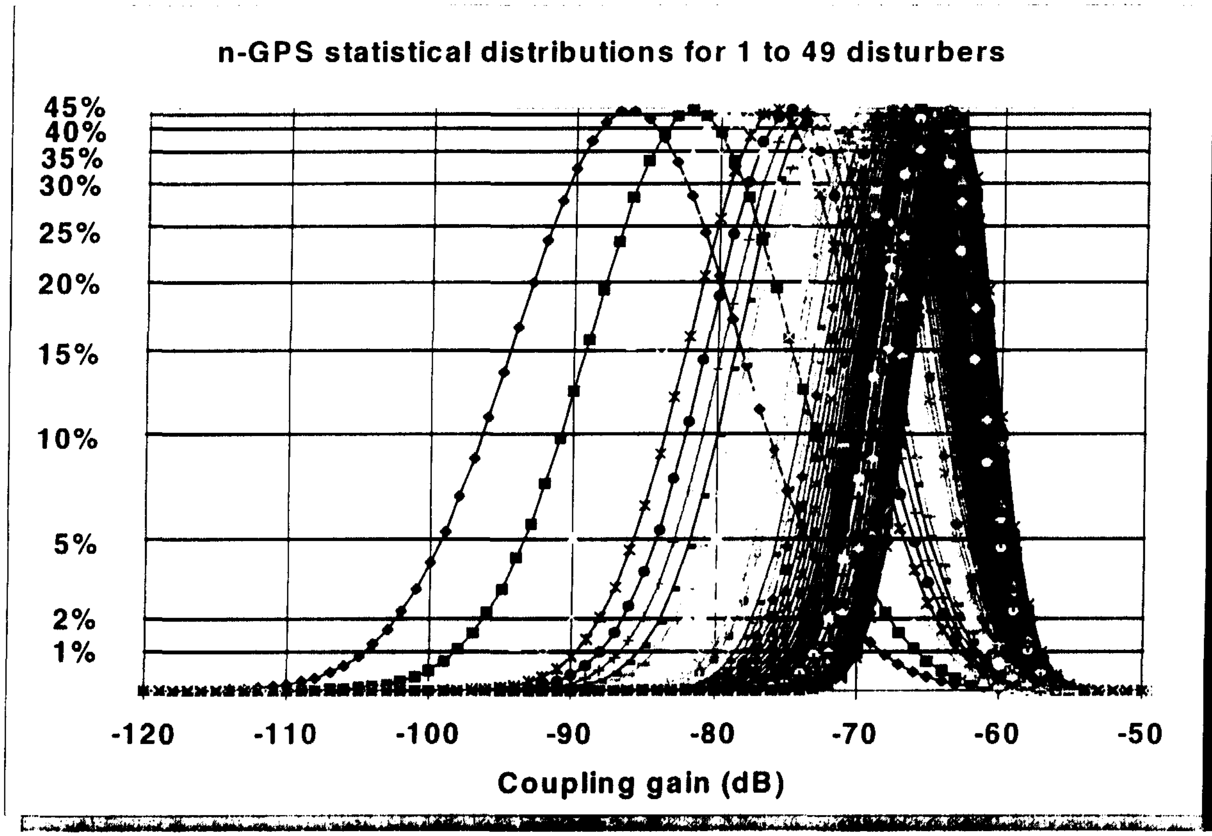

1% worse-case crosstalk model employed to allow for

- robust deployment with minimum of loop engineering
- extended reach
- other impairments (AM radio ingress, in-home wiring, impulse noise, ...)

Receiver Model Definitions

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All systems target operation at at bit-error-rate (BER) of < 10^{-7}

- **ISDN and HDSL**
  - -140dBm/Hz AWGN noise floor
  - 8/64 baud DFE equalizer - mis-equalization effects below noise floor
  - Butterworth low-pass filter
    - 2nd order with f_{3dB} = 80 kHz, for ISDN
    - 4th order with f_{3dB} = 196 kHz, for HDSL

- **T1**
  - -140dBm/Hz AWGN noise floor
  - linear equalizer

Receiver Model Definitions ...

NORTEL NETWORKS

- **FDD DMT ADSL - G.992.2(G.lite) and T1.413(Full-rate)**
  - margin - 6dB (full-rate), 4dB (G.lite)
  - 3dB coding gain
  - user data rate == raw capacity less 32kbps for framing and the lesser of 32 kbps or 10% for FEC overhead
    - the minimum user data rate of 32kbps corresponds to a minimum raw data rate of 96kbps
  - 7 carrier (~30kHz) separation between US and DS bands
  - maximum constellation size 8 bits/carrier (G.992.2 (G.lite)), 15 bits/carrier (T1.413)
  - -140dBm/Hz AWGN noise floor

Performance Benchmarks

NORTEL NETWORKS

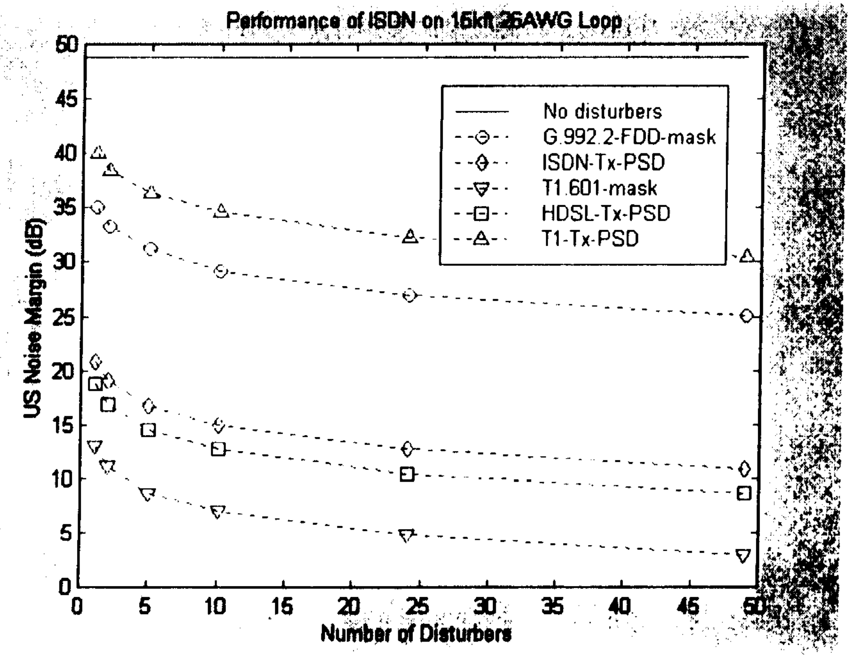
Performance of standard xDSL systems :

- **Noise margin of ISDN over 15 kft 26AWG loop**
- **Noise margin of HDSL over 9 kft 26AWG loop**
- **Noise margin of T1 over 5.28 kft 26AWG loop**
- **Capacity of G.lite Splitterless FDD ADSL over 9 and 15 kft 26AWG loops**
- **Capacity of T1.413 Full-rate FDD ADSL over 9 kft 26AWG loop**

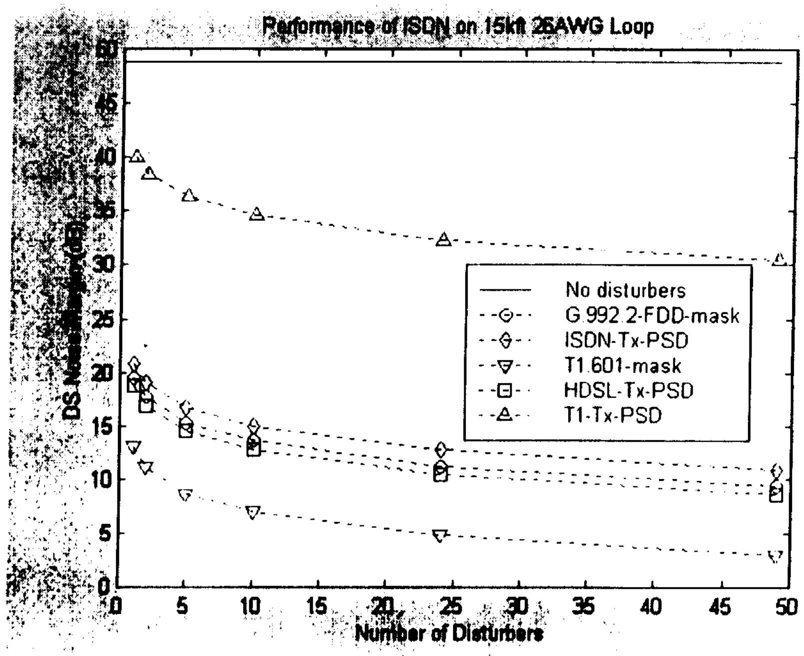
... with crosstalk noise from N = 0, 1, 2, 5, 10, 24 or 49 disturbers meeting proposed reference PSDs

ISDN Noise Margins vs. Disturber Type

Upstream



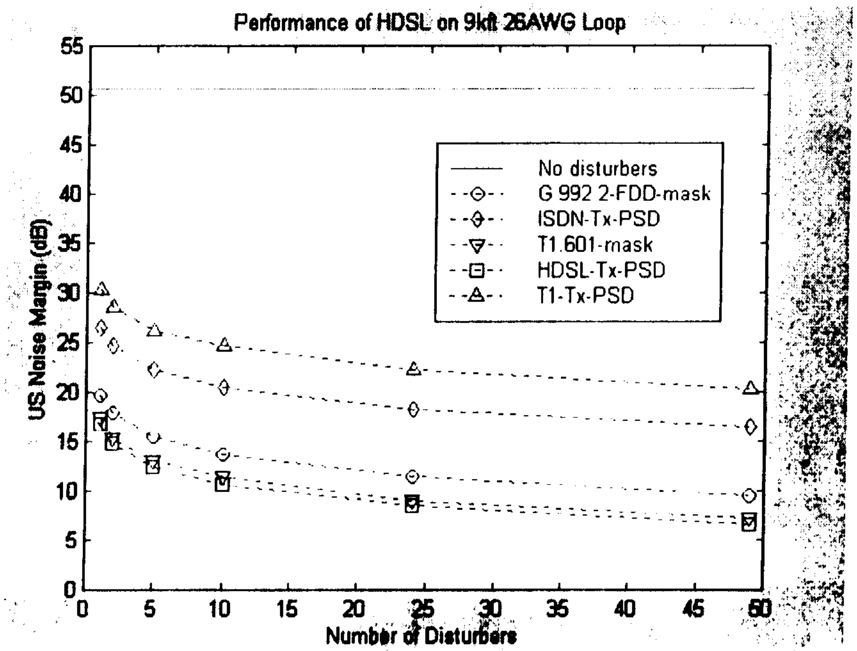
Downstream



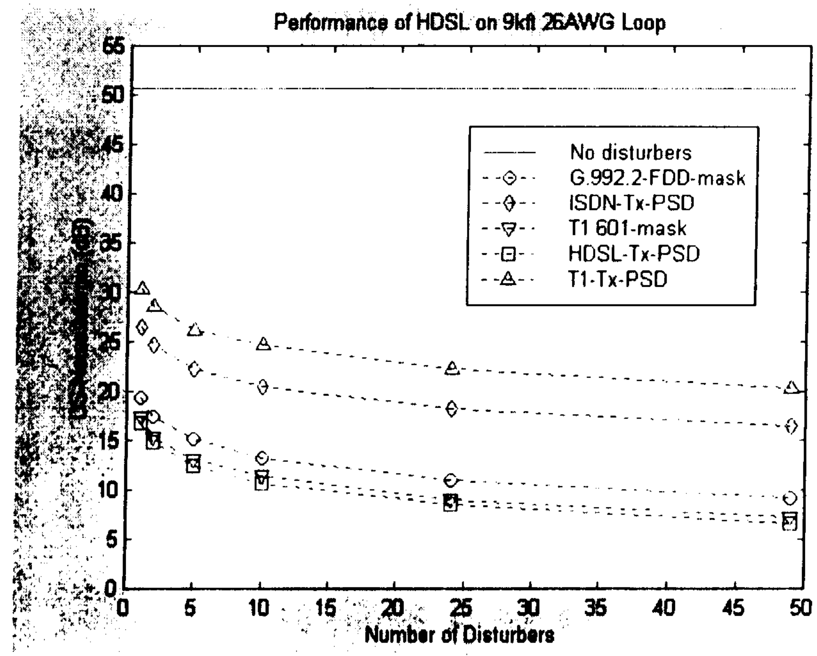
- **Positive margins met with all disturber types, up to N = 49**
- **Disturbers with Tx PSD corresponding to T1.601-mask have a much larger impact on noise margins than a true ISDN signal PSD.**
- **Disturbers with Tx PSD meeting FDD ADSL (T1.413 or G.992.2) mask reduce margin similarly to self-NEXT from other ISDN disturbers in the downstream direction and have basically no effect in the upstream direction.**

HDSL Noise Margins vs. Disturber Type

Upstream



Downstream

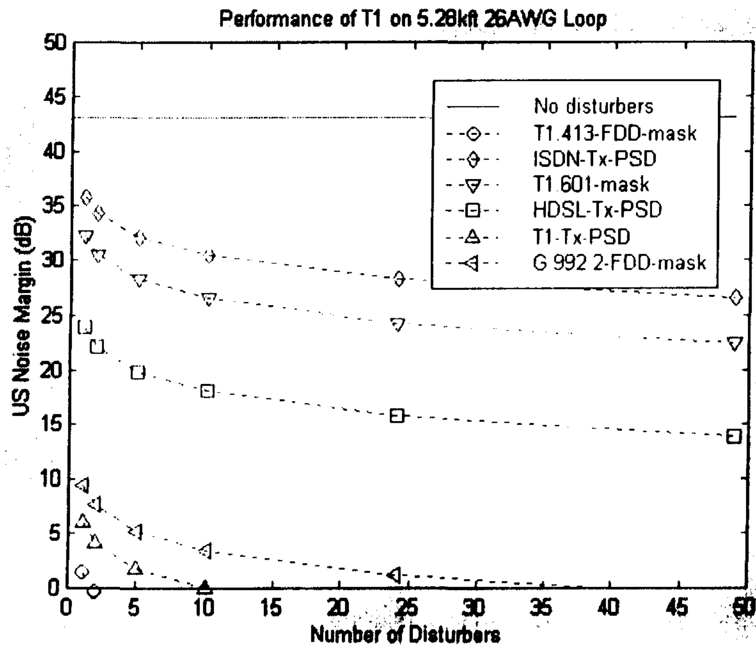


- **Positive margins met with all disturber types, up to N = 49**
- **Disturbers with Tx PSD meeting FDD ADSL (T1.413 or G.992.2) mask reduce margin similarly to self-NEXT from other HDSL disturbers in both directions.**

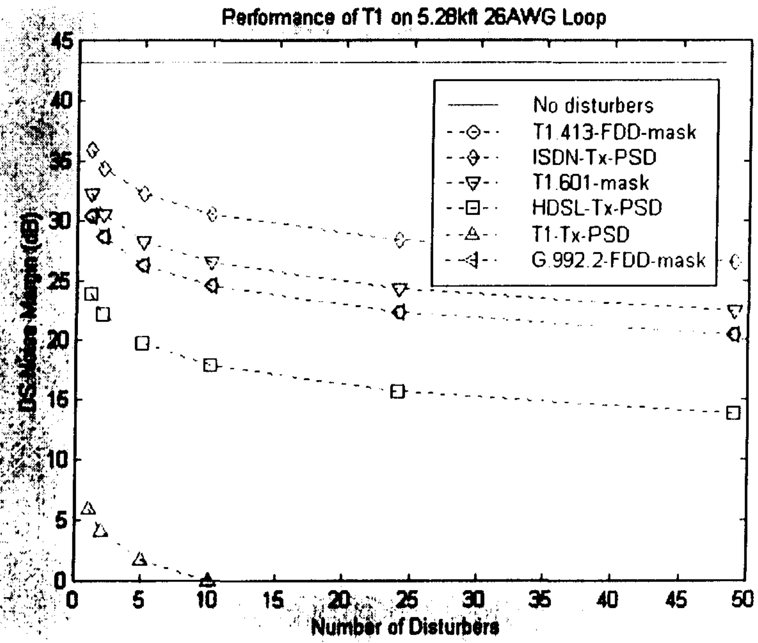
T1 Noise Margin vs. Disturber Type

NORTEL NETWORKS

Upstream



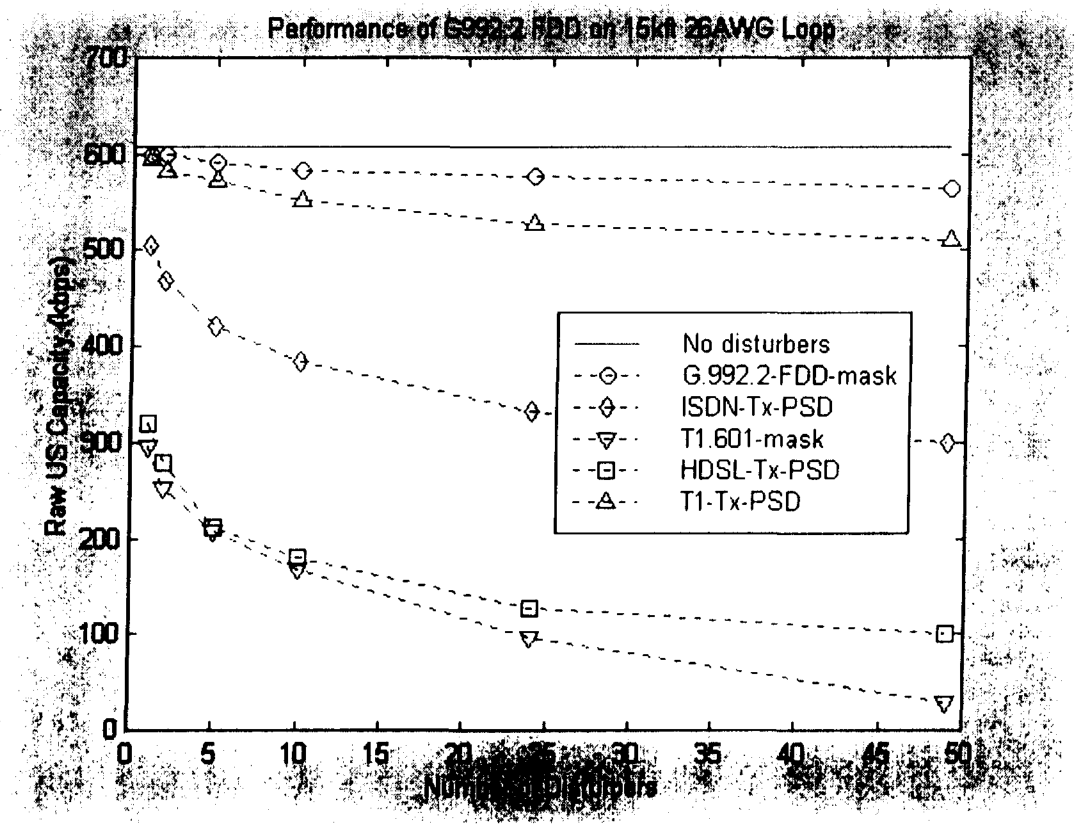
Downstream



- **Margins below or close to zero in presence of an T1.413 FDD mask disturber --> some pairs will not support service**
- **T1s per binder group also limited by self-NEXT between T1 systems**
- **Disturbers with Tx PSD meeting G.992.2 FDD mask reduce margin similarly to self-NEXT from other T1 disturbers.**
- **Better to separate each T1 direction in different binder groups.**

G.lite US Capacity vs. Disturber Type - 15kft Loop

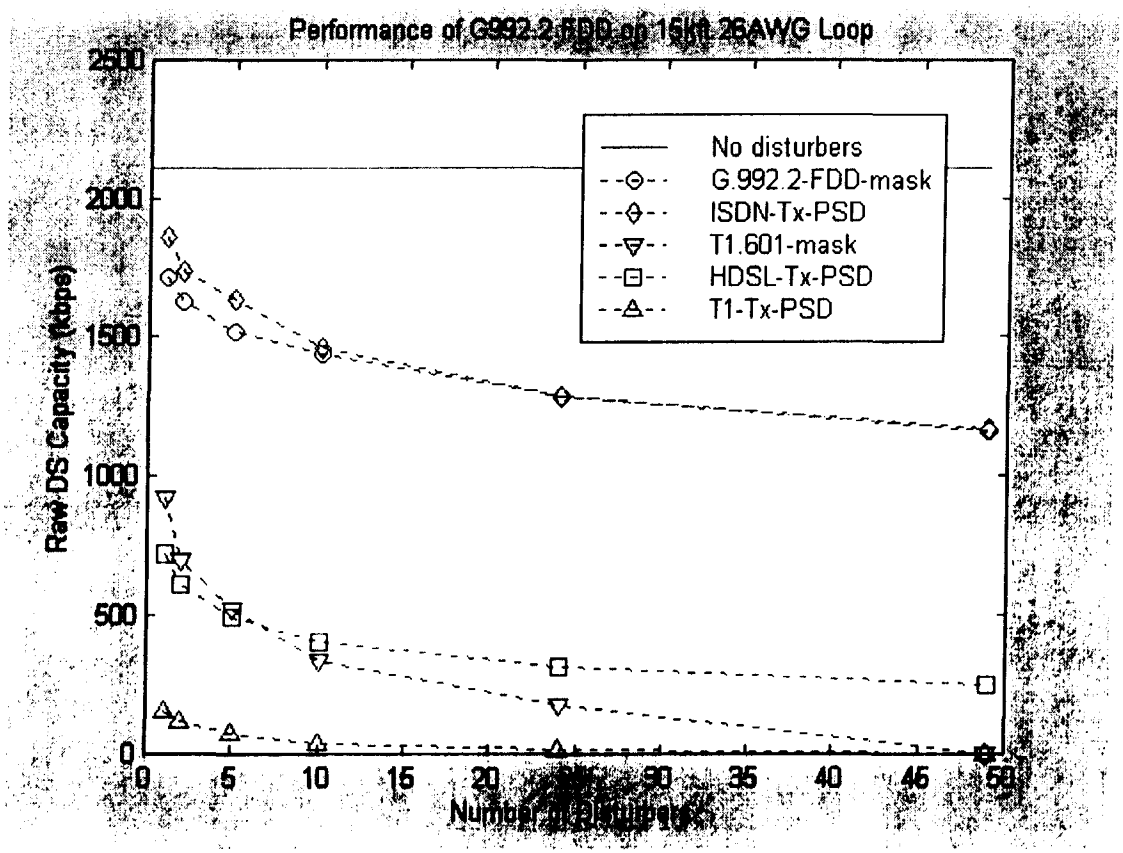
NORTEL NETWORKS



- **Upstream capacity significantly reduced by NEXT from other xDSL systems**
- **Disturber Tx PSDs matching T1.601-mask are most harmful followed by those with HDSL signal PSD and ISDN signal PSD**

G.lite DS Capacity vs. Disturber Type - 15kft Loop

NORTEL NETWORKS

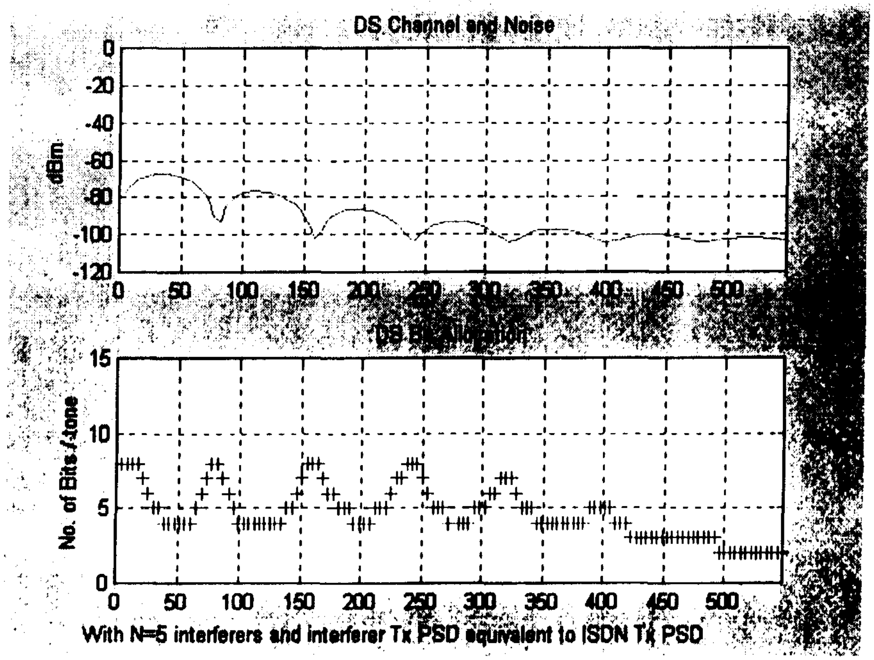


- **Downstream capacity significantly reduced by NEXT from other xDSL systems (in order of 'harm' - T1, T1.601 mask then HDSL)**
- **Disturbers with a T1 signal PSD may prevent service on some pairs**

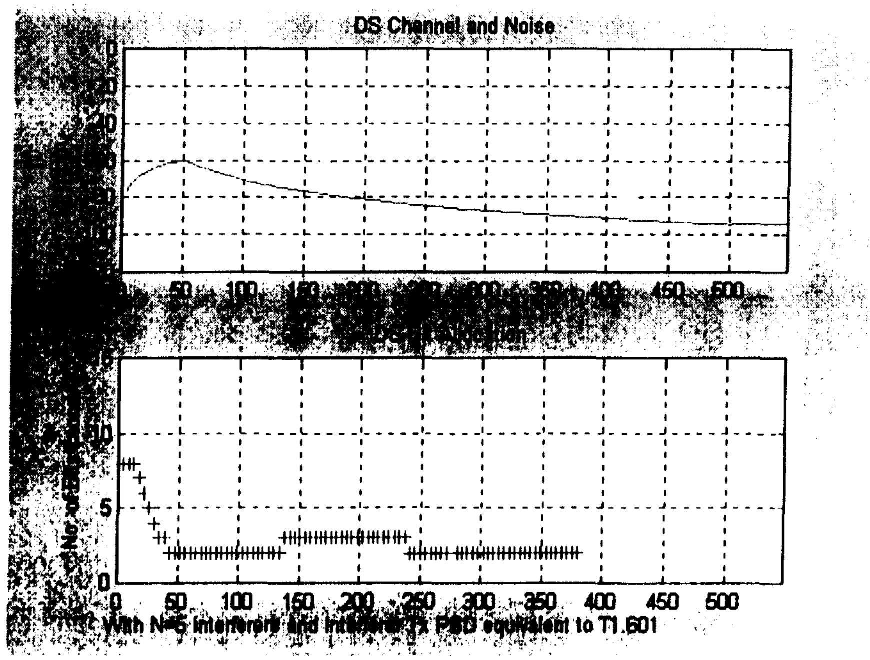
DMT Bit Allocations with ISDN Tx PSD vs. T1.601 Disturbers

NORTEL NETWORKS

ISDN signal PSD Disturbers



T1.601-mask Disturbers

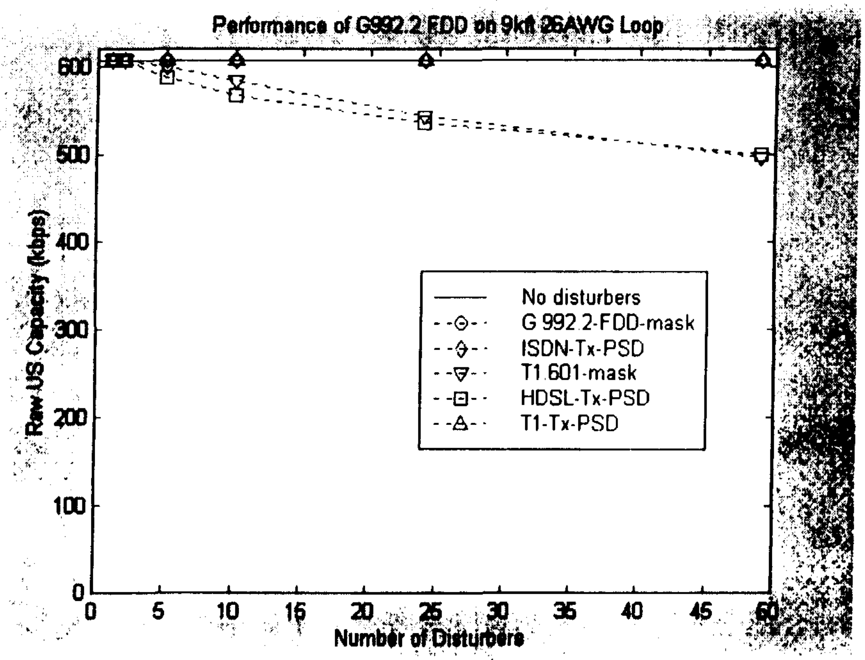


- **DMT systems are able to exploit valleys in crosstalk noise PSD, where they exist (e.g. nulls at multiples of the ISDN transmit baud rate)**
- **T1.601 Mask often 5-10dB above peaks of ISDN signal PSD!**

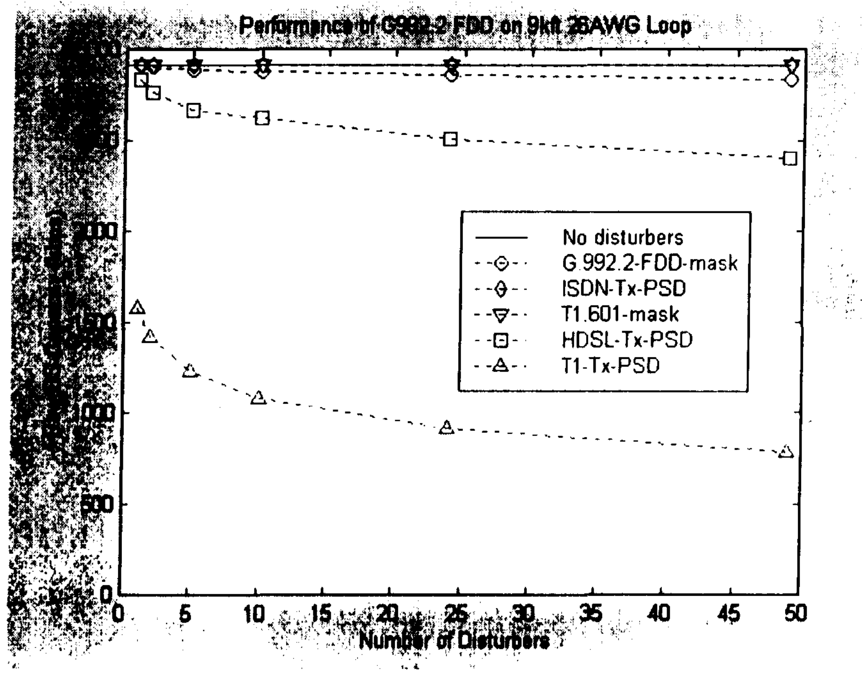
G.lite Capacity vs. Disturber Type - 9kft Loop

NORTEL NETWORKS

Upstream



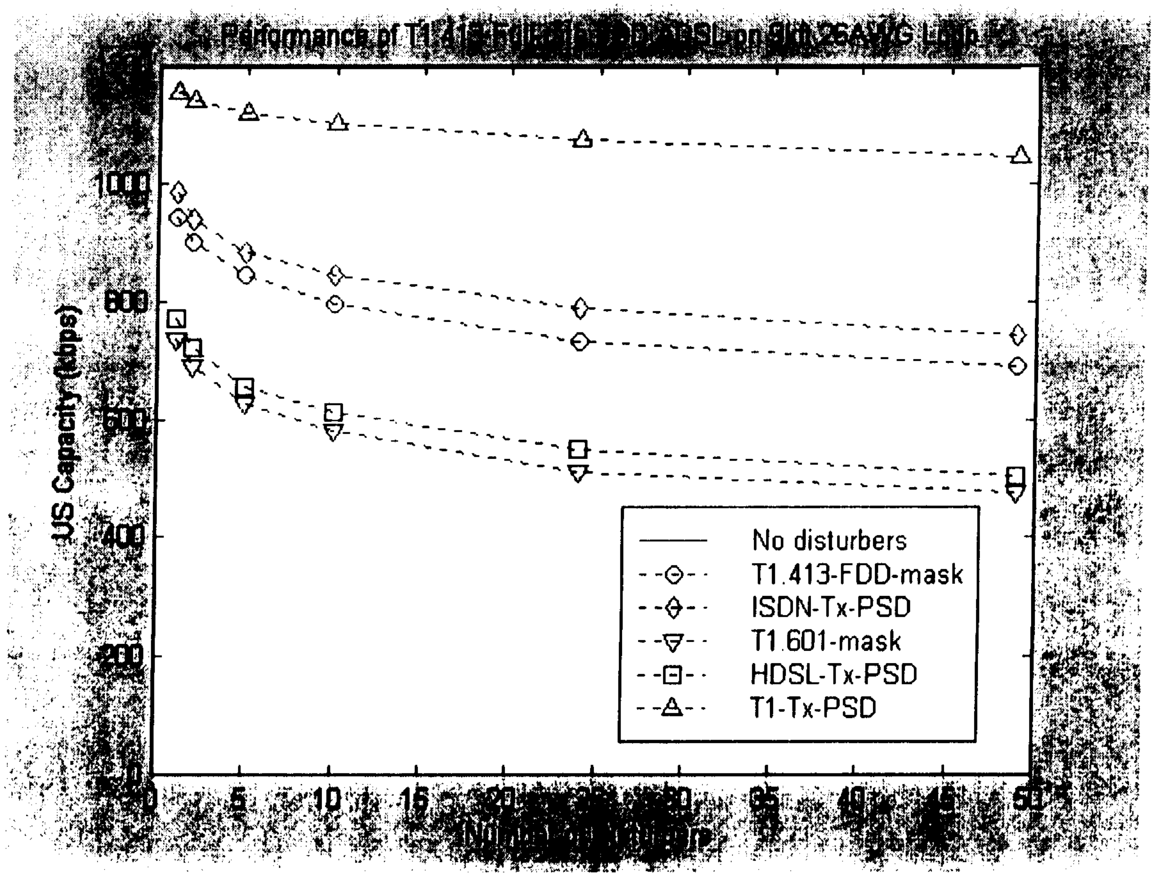
Downstream



- **Crosstalk from other systems has little effect on capacity at this loop length with the exception of T1 in the downstream direction.**
  - Capacity is limited by the constellation size

T1.413 US Capacity vs. Disturber Type

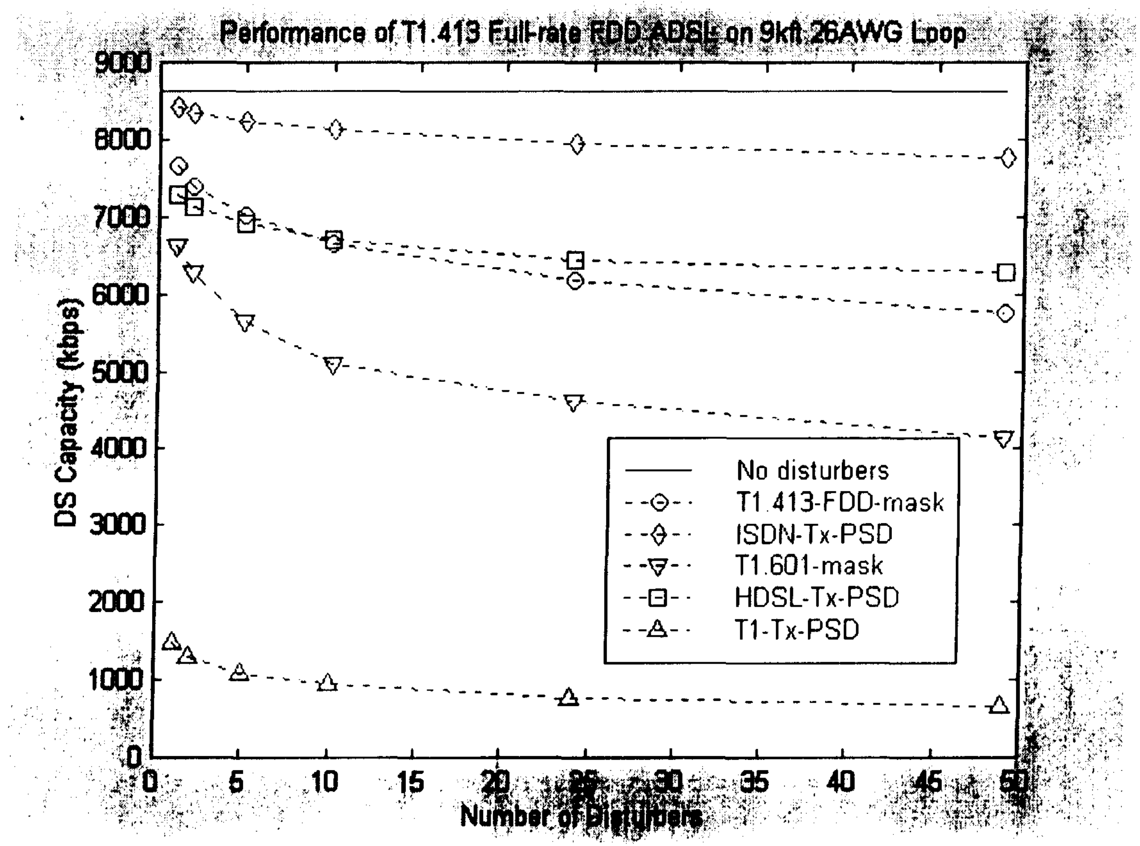
NORTEL NETWORKS



- **Upstream capacity significantly reduced by NEXT from other xDSL systems**
- **Disturber Tx PSDs matching T1.601-mask are most harmful followed by those with HDSL-Tx-PSD**

T1.413 DS Capacity vs. Disturber Type

NORTEL NETWORKS



- **Downstream capacity significantly reduced by NEXT from other xDSL systems (in order of 'harm' - T1 then T1.601-mask)**
- **Disturbers with a T1 signal PSD drop capacity by ~85% vs. crosstalk from systems using the T1.413 FDD mask**

Guidelines A

NORTEL NETWORKS

1) xDSL systems with Transmit PSDs conforming to the G.992.2 (G.Lite) non-overlapped PSD mask should be considered spectrally compatible with existing and emerging xDSL services

2) xDSL systems with Transmit PSDs conforming to the T1.413iss2 (non-overlapped) PSD mask should be considered spectrally compatible with existing and emerging xDSL services, with the exception of T1 lines which should be segregated in a different binder group.

3) New xDSL systems that do not meet the G.992.2 (G.Lite) non-overlapped PSD mask may still be considered spectrally compatible where the vendor provides evidence of its compatibility using methods comparable to those outlined here.
   - standardization of these methods – in T1E1 – are encouraged

Guidelines B

4) Though not as spectrally-'friendly' as G.992.2-compliant xDSLs, HDSL or ISDN may be safely deployed in the same binder group as T1.413-mask-compliant FDD ADSL, where the loops in the binder group are within CSA limits.

- When spectrally-friendly alternatives (to ISDN and HDSL) become available, they may be deployed to maximize the overall capacity of the entire loop plant.

5) A limited number of ISDN DSL systems may be accommodated in the same binder group as T1.413-mask-compliant FDD ADSL, where the loops in the binder group are beyond CSA limits.

- There can be capacity losses; but, these may be considered an acceptable alternatives to the cost of re-engineering those binder groups to separate out those services.

6) Conformance to the T1.601 worst-case PSD mask is not recommended as a useful measure of spectral-compatibility.

- The negative impact of such disturbers is significant greater than that of actual ISDN DSL systems

Guidelines C

NORTEL NETWORKS

7) T1 should not be placed in the same binder group as ADSL.

8) Systems with excess margin (fixed-rate) or capacity (rate-adaptive) should be designed to reduce their transmit power wherever possible to minimize crosstalk into adjacent systems.